INVESTIGATING THE RELATIONSHIP BETWEEN URBAN ENVIRONMENT, AIR QUALITY AND CHILDHOOD ASTHMA: THE CASE OF ANKARA

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ABSTRACT

INVESTIGATIING THE RELATIONSHIP BETWEEN URBAN ENVIRONMENT, AIR QUALITY AND CHILDHOOD ASTHMA: THE CASE OF ANKARA

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Urban environment characteristics have a crucial role in air quality. The geographic location of the city, the natural features and factors brought by this location, and different physical environmental characteristics like street connectivity and land-use mix affect air quality. Some urban environment characteristics can cause more air pollution than the others. Current research shows that children are more affected by air pollution than adults because they breathe more often. This is also why respiratory diseases become chronic during childhood. Asthma is one of the chronic diseases that has increased globally among children over the past few decades. The dynamics of this occurrence indicate that it is the effect of changes in the environment rather than the influence of, for example, age, gender and heredity. Evidence shows that asthma starts in childhood and mostly persists into old age, which explains the importance of focusing on children to decrease the prevalence of asthma in the general public.

Understanding the factors that explain mesoscale urban characteristics that affect outdoor air pollution is essential for planners and designers to develop effective mitigation measures and prevent children's exposure to air pollution. Regarding this, the thesis asked three main research questions: (1) What is the relationship between mesoscale urban environment characteristics and outdoor air quality? (2) Is there a relationship between urban environment-caused outdoor air pollution and childhood asthma? And, (3) What are the physical characteristics of the areas where children are more prone to asthma?

In order to respond these questions, four regions with different urban environment characteristics have been selected in Ankara, Turkey. Next, 800 m radius circles are drawn around each public primary and secondary school, located inside these four regions, to determine the range of children's neighborhoods. The natural environmental characteristics (altitude, temperature, relative humidity, wind speed) and built environmental characteristics (figure-ground, building density, land-use mix, greenness, street connectivity, traffic volume and proximity to industrial areas) of the chosen neighborhoods were analyzed in ArcGIS. Afterward, the streets in these four regions were classified based on their typologies. Measurements of particulate matter (PM10 and PM2.5) were made in the selected streets from each region three times (two on weekdays and one at weekends at peak hours). PM10 and PM2.5 measurements were made with 2 DustTrak II 8530 devices mounted on the hood of the car while traveling by car at min 5 to max 20 speed and stopping for 2-5 minutes at the specified points. Finally, doctor-diagnosed children data of the regions that are registered in Family Public Health Centers was collected from the Ministry of Health. A variety of statistical analysis techniques were used to respond each research question, including pearson correlation and regression.

This thesis contributes to the existing literature by investigating various urban environment characteristics that affect outdoor air quality, the effect of outdoor air pollution on childhood asthma and lastly, the effect of different urban environment characteristics on childhood asthma. The results of the thesis show that the urban environments where children live significantly affect outdoor air quality and childhood asthma. The thesis revealed a significant link between altitude, temperature, and relative humidity from natural environmental characteristics, and

PM10 and PM2.5 concentrations. The built environment characteristics that affect PM concentrations vary depending on different buffer and PM sizes. A positive correlation was found between the number of children with asthma and PM concentrations. As for the urban environment features, it was determined that figure-ground, building density and APOGR (Active-Passive Open Green Ratio) were associated with asthma prevalence. The study's findings led to the conclusion that, in the absence of air quality measures, comparing urban environmental characteristics with data on childhood asthma would not produce reliable results.

Keywords: Urban Environment, Outdoor Air Quality, Childhood Asthma

ÖZ

KENTSEL ÇEVRE, HAVA KALİTESİ VE ÇOCUKLUK DÖNEMİ ASTIMI ARASINDAKİ İLİŞKİNİN İNCELENMESİ: ANKARA ÖRNEĞİ

Aydın, Neşe
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Ocak 2023, 241 sayfa

Kentsel çevre özellikleri hava kalitesi üzerinde çok önemli bir etkiye sahiptir. Kentin coğrafi konumunun ve bu konumun getirdiği doğal faktörlerin, farklı mahalle birimlerindeki sokak bağlantısallıkları ve arazi kullanım çeşitlilikleri gibi farklı fiziksel çevre özelliklerinin kentteki hava kalitesi üzerine etkileri vardır. Kentsel çevre özelliklerinden bazıları diğerlerine nazaran dış ortam hava kalitesi üzerinde daha fazla etkiye sahiptir. Güncel araştırmalar, çocukların daha sık nefes aldıkları için hava kirliliğinden yetişkinlere göre daha fazla etkilendiğini ve solunum yolu hastalıklarının çocukluk döneminde kronikleştiğini göstermektedir. Astım, son yıllarda çocuklarda çok yaygın görülen kronik hastalıklardan biridir. Bu hastalığın prevalansındaki artış, hastalığı tetikleyen faktörlerin yaş, cinsiyet, kalıtım vb. özelliklerden çok yaşanılan kentsel çevredeki değişikliklerin etkisiyle açıklanabileceğini göstermektedir. Kanıtlar astımın çocukluk döneminde başladığını ve çoğunlukla ileri yaşlara kadar devam ettiğini göstermektedir, bu da toplumdaki astım prevalansını azaltmak için çocuklara odaklanılması gerekliliğinin önemini ortaya koymaktadır.

Dış ortam hava kirliliğini etkileyen orta ölçek kentsel özellikleri anlamak, etkili hava kirliliği azaltma önlemleri geliştirmek ve çocukların hava kirliliğine maruz kalmasını

önlemek şehir plancıları ve tasarımcılar için çok önemlidir. Buna bağlı olarak bu tez üç ana araştırma sorusu sormuştur: (1) Orta ölçekli kentsel çevre özellikleri ile dış ortam hava kalitesi arasındaki ilişki nedir? (2) Kentsel çevre kaynaklı dış oartam hava kirliliği ile çocukluk dönemi astımı arasında bir ilişki var mıdır? ve (3) Çocukların astıma daha yatkın olduğu bölgelerin fiziksel özellikleri nelerdir?

Bu soruları cevaplamak için Ankara'da farklı kentsel çevre özelliklerine sahip dört bölge seçilmiştir. Daha sonra, çocukların mahalle mesafelerini belirlemek için bu dört bölge içinde yer alan her bir devlet ilk ve ortaokulunun çevresine 800 m yarıçaplı daireler çizilmiştir. Seçilen mahallelerin doğal çevre özellikleri (eğim, sıcaklık, bağıl nem, rüzgar hızı) ve yapılı çevre özellikleri (şekil-zemin, bina yoğunluğu, arazi kullanım çeşitliliği, yeşil alanlar, sokak bağlantısallığı, trafik hacmi ve endüstriyel alanlara yakınlık) ArcGIS'te analiz edilmiştir. Daha sonra bu dört bölgedeki sokaklar tipolojilerine göre sınıflandırılmıştır. Hava kalitesi -partikül madde- ölçümleri (PM10 ve PM2.5) her bölgeden seçilen sokaklarda üç kez (ikisi hafta içi, biri hafta sonu, en yoğun saatlerde) yapılmıştır. Ölçümler yapılırken bölgelerde bulunan okullar, yeşil alanlar ve benzin istasyonları dikkate alınmıştır. PM10 ve PM2.5 ölçümleri araç ile min 5 - max 20 hız arasında seyahat ederken ve belirtilen noktalarda 2-5 dakika durarak araç kaportasına monte edilmiş 2 adet DustTrak II 8530 cihazı ile yapılmıştır. Son olarak Sağlık Bakanlığı'ndan Aile Halk Sağlığı Merkezlerine kayıtlı olan bölgelerin doktor tanılı çocuk verileri toplanmıştır. Bu veri setlerinin tümü kullanılarak tezin araştırma soruları ele alınmıştır. Pearson korelasyonu ve regresyon dahil olmak üzere her araştırma sorusuna yanıt vermek için çeşitli istatistiksel analiz teknikleri kullanılmıştır.

Bu tez, dış ortam hava kalitesini etkileyen farklı kentsel çevre özelliklerini, dış hava kirliliğinin çocukluk çağı astımına etkisini ve son olarak, farklı kentsel çevre özelliklerinin çocukluk çağı astımına etkisini bularak mevcut literatüre katkıda bulunmaktadır. Tezin sonuçları, çocukların yaşadıkları kentsel ortamların dış hava kalitesini ve çocukluk çağı astımını önemli ölçüde etkilediğini göstermektedir. Tezin sonucunda, doğal çevre özelliklerinden eğim, sıcaklık ve bağıl nemin PM10 ve

PM2.5 konsantrasyonları ile anlamlı bir ilişkisi olduğu, PM konsantrasyonlarına etki eden yapılı çevre özelliklerinin ise farklı buffer-size larına bağlı olarak değişkenlik gösterdiği görülmüştür. Astımlı çocuk sayısı ile PM konsantrasyonları arasında pozitif bir korelasyon tespit edilirken, kentsel çevre özelliklerinden figure-ground, building density ve APOGR (Aktif-pasif açık yeşil alan oranı)'nin astım prevalansı ile ilişkili olduğu tespit edilmiştir. Araştırmanın sonucunda hava kalitesi ölçümleri alınmadan kentsel çevre özellikleri ile çocukluk dönemi astımı verilerinin karşılaştırılmasının doğru sonuç vermeyeceği tespit edilmiştir.

Anahtar Kelimeler: Kentsel Çevre, Dış Ortam Hava Kalitesi, Çocukluk Dönemi Astımı

To my family and friends

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ABBREVIATIONS

WHO : World Health Organization

UN : United Nations

UN-Habitat : United Nations Human Settlements Programme

UNICEF : United Nations International Children's Emergency Fund

SE : Social Ecological

URD : Urban – Rural Differences

TRAP : Traffic - Related Air Pollution

URAP : Urban Environment Related Air Pollution

FPHC : Family Public Health Center

NDVI : Normalized Difference Vegetation Index

OK : Ordinary Kriging

AOGR : Active Open Green Ratio

APOGR : Active – Passive Open Green Ratio

PR : Park Ratio

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Cities have historically been recognized as places for people to come together to enjoy a variety of benefits like socialization and commerce (Frumkin et al., 2004). However, with the invention of the automobile, the focus on connecting people with places has progressively diminished. Places that once provided safe and equitable travel by foot have been increasingly replaced by disconnected land uses and automobile-dependent developments. Evidence shows that such trends in urbanization affect outdoor air quality (Shima et al., 2003).

As urban areas accommodate a growing population, air pollution represents a critical health issue for cities worldwide. A report by the UN Habitat (2022) shows that in 2021, 56 percent of the world's population lived in urban settlements. The same report announced that by 2050, urban areas are projected to house 68 percent of people globally. It is estimated that one in every three people will live in cities with at least half a million inhabitants by the year 2050 (UN-HABITAT, 2022). Additionally, research shows that more than one billion children live in urban areas (here the term "children" refers to individuals in the 0-18 age range) (UNICEF, 2012). This means that one billion children in the world are affected by environmental opportunities and problems, and the advantages and disadvantages of urban settlements. From a demographic perspective, a glimpse into the future shows that the world will continue to urbanize over the next three decades, with urban areas absorbing virtually all the future growth of the world's population (UN-HABITAT, 2022).

Unplanned urban expansion, environmental degradation, public dependence on motorized road transport, and high volumes of freight transport are some of the reasons that cause high levels of air pollution in urban environments (Akilan & Nandhakumar, 2016; UN-HABITAT, 2022; J. Yang & Zhang, 2018). Apart from the built environment of the urban areas, their natural environment also affects air quality (Ramírez-Sánchez & García-Guadalupe, 2013; Wallace et al., 2010). Air pollution can be influenced directly or indirectly by climatic features, geolocation of cities, and meteorological and socioeconomic factors. However, how cities grow and evolve spatially is one of the most crucial components (L. Han et al., 2015; Lu & Liu, 2016). Children living in urban environments are constantly exposed to background levels of several pollutants with a pattern of space (decreasing from the inner city towards the suburbs) and time (more concentrations during the peak hours) variation. Air pollution in urban environments is also a matter of worldwide concern. Hadley et al. (2018) found that, in 2016, globally 4.1 million deaths were attributed to outdoor air pollution and World Health Organization (WHO) reports that 99% of the world population breathes polluted air, exceeding WHO guideline limits. Air pollution's impact on health is appraised to be as great as other major global health risks such as tobacco use and obesity (WHO, 2009). Nevertheless, air pollution is not something that populations can escape.

Urban air quality studies have shown that some gases and particles negatively impact human health. Urban air pollution can penetrate the bloodstream and affect all organ systems (WHO, 2009). The impacts of air pollution can be either transitory (e.g. coughing) or long-term and irreversible, ranging from cardiovascular and respiratory disease, lung and other cancers, asthma and other non-communicable diseases (NCDs), poor birth outcomes, and developmental challenges. Air pollution, and in particular its fine particulate component, has recently been classified as a cause of lung cancer (IARC, 2013). According to the WHO (2018), air pollution (both indoor and outdoor) is linked to 7 million premature deaths annually and a substantial reduction in years of healthy life.

There is growing evidence that air pollution affects children's neurological development (Guxens & Sunyer, 2012; Künzli et al., 2010). In a report published in 2018, WHO estimated that 93 percent of the world's children are exposed to toxic air daily, putting their health at risk. Acute lower respiratory infections caused by polluted air have been linked to the death of 600,000 children in 2016 (WHO, 2018). Over the past few decades, allergic disorders have become much more common, particularly in children and young adults (Pawankar, 2014). The dynamics of this occurrence indicate that it is the effect of changes in the environment rather than the influence of personal factors like age, gender and heredity.

Air pollution affects children more significantly due to their relatively higher ventilation and metabolic turnover (Tzivian, 2011). Children's immune systems are not fully developed, and thus the incidence of respiratory infections is high. The lung is still growing, and any deficit in growth will be relevant throughout the child's life (Perez et al., 2010). This poses a threat to children living in environments with intense air pollution; with the inhalation of particles and gases in the air, air pollution can trigger asthma – one of the most devastating chronic diseases in children (Arrieta et al., 2015; Asher & Pearce, 2014a; Graham, 2004). Several cross-sectional studies from Germany, Switzerland, France, and the USA found that compared to their peers who live in less polluted regions, school-age or pre-school children who live in communities with higher levels of dust, SO2, and NO2 suffered more from cough, acute bronchitis and asthma (Gern, 2010; Gern et al., 2009; Künzli et al., 2010; Lynch et al., 2014; Perez, Lurmann, Wilson, Pastor, Brandt, Künzli, et al., 2012).

Asthma is one of the most common health problems of the 21st century (Hoffjan & Ober, 2002; Lai et al., 2009). Asthma can trigger other health problems, reduce the quality of life and economic status of individuals, and even results in death (Busse et al., 2000; O'Connell, 2004). Studies conducted across the globe show that the number of children with asthma is increasing dangerously year by year (Akinbami et al., 2016; Asher & Pearce, 2014b). One of the crucial factors triggering asthma is outdoor air quality (Graham, 2004; B.-F. Hwang et al., 2005; Sobral, 1989). Compared to other age groups, children are found to have the highest incidence of asthma (Olin & Wechsler, 2014). According to the International Study of Asthma and Allergies in Childhood (ISAAC), 11.6% of children aged 6-7 years worldwide had doctor-diagnosed asthma in 1995 (ISAAC Steering Committee, 1998). In studies conducted with the ISAAC method in Turkey, it has been found that approximately 15 children out of every 100 children have doctor-diagnosed asthma in the 2000s (Karaman et al., 2006; Mutlu & Balci, 2010). Also, in a study conducted in 2003 in Ankara (which used the ISAAC method), Saraçlar et al. (2003) found that the prevalence of physician-diagnosed asthma in schoolchildren aged 8–11 years was %6,9. Evidence shows that asthma starts in childhood and mostly persists into old age (Burgess et al., 2007; McMichael, 2001; Reed, 2006)– a finding which explains the importance of focusing on children in order to decrease the prevalence of asthma in the general public. Asthma cannot be cured, but its effects can be reduced and even prevented from appearing if necessary precautions are taken.

Current research shows that children living in the city are more likely to have asthma than those living in the urban periphery, where construction and vehicle traffic is less frequent (Crain et al., 1994). Similarly, street patterns that prevent wind flow and cause exhaust emissions undoubtedly pose a severe threat to the health of children who actively use the street. In addition, air pollution remains in the street because of the form of urban neighborhoods (e.g., building form, building density) and other physical environmental factors (like the presence of large amounts of paved surfaces) that prevent airflow and cause heat islands. Spending time in a street environment, especially after school and in the evening when vehicle traffic is the busiest, exposes children more to the side effects of air pollution (Graham, 2004). Frank et al., (2007) determined that increasing the walkability index (measured by changes in urban form elements such as increasing land use diversity and building density) of a neighborhood by 5% enables each person to travel 32.1% more actively (walk or bike more when getting from one point to another), travel 6.5% fewer kilometers by car, and thus have 5.6% less nitrous oxide and 5.5% less volatile organic matter into the air. This study shows that urban planning and design practices affect the outdoor air quality in neighborhoods by influencing the urban form.

To sum up, the literature approves that the urban environment characteristics directly affect outdoor air pollution and this problem directly affects childhood asthma. However, there are still great deficiencies in the literature about the indirect relationship between urban environment and childhood asthma caused by outdoor air pollution, specifically on which mesoscale urban environment characteristics affect childhood asthma. There are many studies and projects about the relationship between asthma and the urban environment (Crain et al., 2002; Gern, 2010; Gern et al., 2009; Phipatanakul et al., 2011; Wright et al., 2011) but they usually focused on the health side of the relationship, not the natural and the built environment side. This is partly because, until recently scholars who approached this link have been largely affiliated with health sciences. This study is going to focus on the urban environment side of this relationship from the perspective of an urban planner.

1.2 Aim and Research Questions of the Study

This research aims to understand the preventable spatial risk factors of childhood asthma, which is one of the serious public health problems and to understand the urban environment characteristics that cause these problems. It aims to contribute to urban planning and public health literature by informing planners, designers, policy-makers, and developers about how to create neighborhoods where cleaner air can be breathed. It seeks to understand what changes should be made in the physical environment of cities in order to prevent the triggering of asthma. Therefore, in general, this thesis aims to help urban planners and designers in creating healthy cities for all.

This research explores the relationship between the urban environment, air pollution, and childhood asthma at different levels. The study asks the following research questions:

1. What is the relationship between mesoscale urban environment characteristics and outdoor air quality?

    a. Which features of the urban environment significantly affect outdoor air quality?

    b. Do urban spots with less or more air pollution show a differentiation based on the urban environment characteristics of their surroundings?

2. Is there a relationship between urban environment-caused outdoor air pollution and childhood asthma?
    a. Are children diagnosed with asthma living in environments with more intense air pollution?
3. What are the physical characteristics of the areas where children are more prone to asthma?
    a. Which urban environment characteristics play a role in promoting childhood asthma?

Meso scale is an urban scale that sits in between micro and macro scale. Micro scale refers to the area immediately surrounding a person's home (or work or goes to school). Even people who reside on the same street could have different micro environments. Meso scale is a term to describe small-scale areas where people reside, such as a neighborhood or census block group. Larger size locations, such as cities or counties, are represented by macroscale environments. (Day, 2018). Within the scope of this study, the locations of traffic lights, that may affect the air quality, the presence of a median on the road, the types of trees in the study areas, the pavement situation in front of the residences, etc. that may affect the air quality on a point scale are not covered. Neither are the geographic location of the city, the soil structure and climate characteristic of the whole city of Ankara that may affect the air quality on a regional scale. Meso-intermediate-scale urban environment characteristics are specifically discussed within the context of this thesis. Urban environment, as is used in this thesis, refers to the physical (natural and built) characteristics of urban areas. In order to represent the meso-scale urban environment charactersitics, within the scope of this thesis, altitude and meteorological information are taken as natural characteristics; figure-ground, land use mix, building density, street connectivity, traffic volume, open-green areas and distance to the nearest industrial areas are taken as built environment characteristics. Previous resesearch has examined whether some of these natural and built environment variables (like traffic volume and distance to industrial areas) affect outdoor air quality. With this thesis, it will be possible to determine whether these elements that affect air quality have an impact on asthma in children as well.

It is intended to provide guidance to city planners and designers regarding problematic areas, and how these areas can be improved in the context of improving air quality so that these areas can be used more effectively. It also aims to provide guidance regarding the types of planning and design practices that should be used in order to improve the outdoor air quality in newly constructed settlements.

1.3 Gaps in Theory and Research

When the literature on the relationship between the urban environment, outdoor air quality and childhood asthma is examined (articles on the subject, which were published in English and that were retrieved from Google Scholar, WOS, Scopus and PubMed), it is seen that no study has every investigated such a triangular relationship. Additionally, most of the existing studies on urban environment and childhood asthma or outdoor air pollution and childhood asthma have been done by medicine and health disciplines; there has been no study on this subject by city planners and urban designers. As far as we know, this thesis will be the first study on this subject by a city planner. From this perspective, the 2nd and 3rd research questions we asked within the scope of the thesis will be evaluated for the first time from a planner's point of view.

The majority of the existing studies on ‘urban environment and outdoor air pollution’ and ‘urban environment and childhood asthma’ focused on urban-rural contrasts and traffic-related air pollution (Alotaibi et al., 2019; Ciccone G et al., 1998; Hwang et al., 2011; Shima et al., 2003). Studies that focused on the health outcomes of the characteristics of urban environments by and large examined how the NDVI (Cavaleiro Rufo et al., 2021; W. Huang et al., 2021) and land-use mix (Paciencia et al., 2022) affect childhood asthma at the urban scale. There is only one study in the examined literature that examines air quality at the neighborhood level (Corburn et al., 2006). Cornburn et al.'s (2006) study was carried out by calculating the density of land uses that are known to be hazardous and have a negative impact on air quality. This thesis, to the best of author's knowledge, will be the first study to examine how a variety of urban environmental characteristics (the features that can affect air quality both positively and negatively) affect both outdoor air quality and childhood asthma.

There are relatively few studies looking at the connection between the urban environment and outdoor air quality at the street scale, as will be discussed more in detail in the following chapter of the thesis. Studies done at the street scale in the literature have only looked at one location (Bouhamra & Abdul-Wahab, 1999; M. Liu et al., 2021) and have not compared streets with diverse physical characteristics. This study aims to fill out this gap in the literature. The first research question posed in this thesis aims to help us understand how air quality varies from one side of the street to another as the urban form characteristics changes.

1.4 Assumptions of the Study

For each research question, this thesis has a different assumption, all of which were generated by utilizing the information acquired from the existing literature and theories. In the conclusion chapter of the thesis, the author aims to interpret the findings of the research by referring to these assumptions.

The assumption for RQ1.: The mesoscale urban environment characteristics have an effect on air quality. To the best of our knowledge, no study has been done on how environmental characteristics affect street-level air quality and, consequently, childhood asthma, as the author specified in the title above. However, research comparing urban and rural environments on a larger scale has shown that urban environments, as opposed to rural ones, have detrimental effects on outdoor air quality as a result of traffic density, building frequency, industrial zones, etc. (Forastiere et al., 1992; Odhiambo et al., 1998; Yemaneberhan et al., 1997). In light of this information, it is assumed that urban environments have an effect on outdoor air pollution. In addition to this general assumption, this thesis has several assumptions regarding the effect of each of the investigated urban environment characteristic on outdoor air quality. These assumptions are as follows:

- The researcher assumes that high-altitude regions will be better in terms of air quality. According to the literature, places at higher altitudes have more air flow, which results in less PM10 and PM2,5 (Particulate Matter) concentrations (Ning et al., 2018). Also, a street-scale research that assessed air pollutant concentrations at 0 m and 35 m heights of the same spot on rainy and non-rainy days, discovered that measurements obtained at 35 m had lower concentrations under all circumstances (Warlina et al., 2019).
- The researcher assumes that air pollution is less in areas with low temperature, high relative humidity and high wind speed. The literature proves that as temperature decreases PM10 concentrations decrease (S. Kim et al., 2015), as relative humidity increases air pollutant concentrations decrease (Wu et al., 2022), as wind speed increases air pollutant concentrations decrease (J. Yang et al., 2020).
- The researcher assumes that higher void spaces mean higher air quality in the studied regions. Because void areas are assumed to facilitate air flow (Sarı & Aybek, 2018) .
- The researcher assumes that air pollution will increase as the building density increases. Because it has been proven that the number of floors of the buildings affects the wind direction and speed (J. Yang et al., 2020), thus

causing the formation of urban heat islands (Liang et al., 2021) and affecting the air quality.

- The researcher did not make any assumptions regarding how land-use mix would affect air quality in light of the literature. The findings in the literature about land-use mix and air quality are contradictory. For instance, Bechle et al. (2011), employing satellite images, found that cities with moderate to highly crowded, compact, and high land use diversity had higher air quality than those with less dense, fringed (non-compact), and sparse land use. Similar findings were made by McCarty and Kaza (2015), who discovered that the urban environment's fragmentation makes the city's outer suburbs' air quality poorer. Some researchers have determined that practices that increase physical activity, such as increasing building density and preventing urban sprawl, increase air pollution. For example, Stone and Rodgers (2001) and Zhang and Gu (2013) found that denser and more compact cities have more building surfaces, resulting in increased heat absorption. They discovered that pollutants such as carbon monoxide (CO) and particulate matter (PM) cause them to hang in the air, which causes more harmful pollutants to be inhaled while walking on the street.

- The researcher assumes that regions with more open and green areas will be better in terms of air quality. Although the formulas used within this research didn't used in any research before, studies using NDVI proves that as green index increases air pollution decreases (Gajjar et al., 2021; Zhan et al., 2018).

- The researcher assumes that being near industrial areas has detrimental effects on air quality. The literature has proven that industry causes air pollution and this air pollution has negative effects on human health (Morin et al., 2012; Pope, 1989).

- The researcher did not make any assumptions regarding how street connectivity would affect air quality. As is mentioned in the land-use mix analysis part, street connectivity is also about compactness, and there are conflicting results in the literature on the air quality of compact areas. The goal of this analysis is to produce findings that will aid in resolving the literary disagreement.

- The researcher assumes that air pollution concentrations will be higher in areas with heavy traffic. There are many studies in the literature that say that traffic is one of the factors that cause air pollution (Dastoorpoor et al., 2016; Lockhart et al., 2015; Soegoto et al., 2019).

The assumption for RQ2.: Outdoor air pollution caused by the urban environment worsens childhood asthma. It has been demonstrated in the literature that outdoor air pollution negatively affects children's asthma (Friedman et al., 2001; Hirshon et al., 2006; W. Huang et al., 2021). Based on this information, it was assumed that urban-environment caused outdoor air pollution would adversely affect childhood asthma.

The assumption for RQ3.: Urban environment characteristics which cause bad air quality have an effect on childhood asthma. As it was mentioned above, there is only one study in the literature that examines urban environment characteristics at the neighborhood level (Corburn et al., 2006). The results of the study show that noxious land uses tend to cluster in areas with elevated asthma hospitalization rates. This evidence led to the assumption that children who live in areas with low air quality are more likely to develop asthma. The researcher assumes that urban environmental features, which she hypothesized to cause air pollution, also trigger asthma.

1.5 Research Methodology

This study is an interdisciplinary exploration, drawing topics that have been studied in different disciplines, including city and regional planning, environmental engineering and health. Although the meanings of various terms that have been used in these disciplines are defined throughout the thesis whenever necessary, they are presented collectively in Appendix A.

The research is focused on the city of Ankara to examine the relationship between the urban environment, air quality and childhood asthma. Ankara is among the cities in Turkey where asthma and air pollution are seen intensely. It is one of the largest cities in Turkey, which has various neighborhoods with different urban environment characteristics. Considering the number of people diagnosed with asthma in hospitals in 2013 by provinces, it is seen that Ankara is among the nine cities with the highest diagnosis of asthma cases (Al & Özcebe, 2017). A survey conducted in Ankara shows that the prevalence of asthma in primary school children was %8,3 in 1992 and %9,8 in 1997 (Kalyoncu et al., 1994, 1999). According to the 2018 air pollution report prepared by the Chamber of Environmental Engineering, Ankara is one of the cities that has the highest pollution rates in Turkey in terms of outdoor air pollutants; PM2.5, PM10, No2, Nox. Therefore, the author considered this city to be an ideal case for investigating the relationship between urban environment characteristics, air quality and childhood asthma.

Eight neighborhoods in four different regions in Ankara have been selected within the scope of the research. While choosing these neighborhoods, three criteria were taken into consideration. The first criterion was the urban environment characteristics of neighborhoods. The site selection was made according to the mesoscale urban environment characteristics of neighborhoods. The area selection was made in line with the readily accessible online data. Detailed analyses of the form characteristics of the chosen neighborhoods were made after the neighborhood selection process. The second criterion was the results of the literature review on the relationship between urban environment, outdoor air quality and childhood asthma. For example, the size of the study areas and the form characteristics to be examined within the scope of this thesis were determined by refetting to the findings in the literature. The third and final criterion was the availability of primary and secondary public schools in the selected study areas. The geographic extent of the neighborhoods is defined by public primary and secondary schools in the neighborhoods. School children between the 7 and 12 age groups, who go to primary and secondary school, are considered as childhood in this study. This is due to the fact that the Ministry of Health's data separated the children into two age groups: 0–6 and 7–12 years old, and 0-6 age group is children who have not yet started school.

The schools in selected neighborhoods are detected, and 800 m circles are drawn from these schools. Davison & Lawson, (2006) detected that, children were less likely to actively commute to school if their route is more than 800 m, and this research tries to represent the children who spent time outdoors in the selected neighborhoods. Placing circles with a radius of 800 meters around public schools made the study independent from the administrative boundaries of the neighborhoods, which had no determination criteria other than the minimum population (Municipal Law, 2005). All of the analyses are made within the regions created with 800 m buffer borders.

This thesis employed both primary and secondary data. The term "primary data" refers to information gathered from a fieldwork. First of all, a fieldwork was carried out in order to transfer the features to be used in the urban environment analysis of the boundaries of the selected neighborhoods as defined by school-based circular buffers to the GIS environment. For this purpose, initially, the existing drawings were obtained from the Ankara Metropolitan Municipality. Then they were updated by using satellite images and site excursions. The other primary data that is used in the thesis is air quality measurements. Air quality measurements were made with two air quality devices (Dust Trak II 8530). The measurements were taken by two different methods. First, by fixing the devices to an automobile while driving. Second by placing the devices at a fixed point for 24 hours.

Secondary data refers to data that was obtained from different sources and not directly collected by the researcher. Temperature, humidity, wind direction, and speed data were obtained from the General Directorate of Meteorology for the days when air quality measurements were taken. In addition to meteorology data, traffic data was taken instantly from Yandex Maps. Health data were obtained from the Ministry of Health. This data includes information about asthmatic patients and total registered patients aged 0-6 and 7-12 years old to Family Public Health Centers located in or near the study areas.

After obtaining all the necessary data for the study, the obtained data were examined by comparing them with each other by using a mixed-methodological approach. Urban environment and air quality data were used to answer the first research question and test the assumption. Air quality and health data were used to answer the second research question. In order to answer the third research question, the researcher used the urban environment and health data. This thesis proposes a novel interdisciplinary methodology where detailed urban environment, air quality, and health data were combined.

1.6 Configuration of the Thesis

This thesis is composed six chapters. The introduction chapter is a brief summary of the thesis. It includes the aim and context of the research, the research questions, the assumption of the research, and finally, the methods used in the research.

The second chapter consists of the literature review conducted within the scope of this study. Since this thesis aims to investigate the relationship between three concepts – urban environment, outdoor air pollution and childhood asthma – and since no study has ever investigated the link between these three concepts, the author reviewed the existing literature on:

1. urban environment and outdoor air pollution,
2. outdoor air pollution and childhood asthma,
3. urban environment and childhood asthma.

At first, the thesis reviewed the literature on the direct relationship between urban environment and outdoor air pollution. Then it focused on the literature about the direct relationship between outdoor air pollution and childhood asthma. Finally, it reviewed the literature on the indirect relationship between urban environment and childhood asthma.

Chapter three introduces the study's research method and design, including the methods of data collection, processing, editing and analysis. Research methodology is designed to explain the relationship between the urban environment, outdoor air quality and childhood asthma by addressing the main research questions, sub-questions, and assumptions. The data collection and data analysis procedures to measure variables and the research approach of the study are described in this chapter.

Chapter four is the chapter where the results of the study are presented. The chapter is designed in three sub-chapters, all of which are designed to answer each research question. The first sub-chapter is about the relationship between urban environment and outdoor air quality. The second sub-chapter is about the relationship between outdoor air quality data and childhood asthma. Finally, the third sub-chapter is about the relationship between urban environment characteristics and childhood asthma.

Chapter five discusses the relationships that have been proven within the scope of this study (the relationship between urban environment and outdoor air quality / the relationship between outdoor air quality and childhood asthma / the relationship between urban environment and childhood asthma. The main discussion of the research questions based on the literature is placed in this section.

Chapter six concludes the thesis, summarizing and providing insights into the research's general findings. This last chapter also includes the implications for city planning and urban policy, information about the contribution of this research to the existing knowledge, the limitations of the research and suggestions for future research.

CHAPTER 2

A THEORETICAL FRAMEWORK FOR UNDERSTANDING THE LINK BETWEEN URBAN ENVIRONMENT, OUTDOOR AIR QUALITY AND CHILDHOOD ASTHMA

This study questions the relationship between the urban environment, outdoor air pollution, and childhood asthma. To this end, firstly, the main theories that explain the relationship between the physical environment and public health are introduced, the role of city planning within these models is discussed. The section also informs about the relation between city planning and public health. This section once again highlights that the environments where residents live have a significant role in affecting outdoor air quality and thus their health status.

The second section reviews the literature on the relationship between the urban environment and outdoor air pollution. As the review shows, there is a great deal of literature that has examined this relationship without questioning the health outcomes of living in particular places.

In the third section, the author reviews the literature on the relationship between outdoor air pollution and childhood asthma. Findings show that the role of the built and natural environment has been ignored in many studies, perhaps because many of them have been conducted in the fields of medicine and public health. However, the review informs researchers about which pollutants have been measured and what methods have been used so far for detecting asthma.

Lastly, the literature on the relationship between urban environment and childhood asthma has been reviewed. While doing the review, the author questioned which characteristics of the urban environment have been investigated in relation to childhood asthma. If any triangulation has been made between the built environment, outdoor air pollution, and childhood asthma in any study, once again, the author reviewed which pollutants were measured and what methods were used for detecting asthma. The supporting tables in Appendix B provide a detailed summary of this review.

2.1 The Link Between Physical Environment, City Planning, and Public Health

There are different socio-ecological (S.E.) models that hold the impact of the social and physical environment on public health (Burke et al., 2009). One of the origin studies on this subject is Bronfenbrenner (1979). Bronfenbrenner investigates the role of macrosystem, exosystem, and mesosystem environments in human development. The writer precisely focuses on the children, their environment and the effect of this environment on their development.

Ecological models, as they have evolved in the behavioral sciences and public health, emphasize the nature of interactions between people and their physical and sociocultural environments (Stokols, 1992). S.E. models are based on the idea that the physical and social environments have a variety of effects on individuals' health (J. F. Sallis & Owen, 2015). To deal with the evolution of S.E. models from the past to the present and to determine which model variables are addressed by this thesis, a few models will be reviewed.

Stokols (1992) defines how a variety of personal and environmental factors affect one' health and illness. He describes each S.E. factor that has an effect on health. However, the relationships between these factors are missing in his model. The model discussed biopsychobehavioral and sociophysical environmental factors that may cause public health problems but did not address how these factors might do so. While Stokols (1992) deals with biogenetic, psychological and behavioral factors under the title of biopsychobehavioral, he discussed geographic, architectural and technological and sociocultural factors under the title of sociophysical environment. The issue of air pollution, which is discussed within the scope of this thesis, is discussed under architectural and technological factors in this model. Relevant areas are shown in the model with a red frame (see Figure 1).

Personal and Environmental Factors in Health and Illness

Biopsychobehavioral factors			Sociophysical environmental factors		
Biogenetic	Psychological	Behavioral	Geographic	Architectural and technological	Sociocultural
Family history of illness	Sense of coherence	Dietary regimens	Climatic and geologic risks (e.g., earthquakes, floods, hurricanes, tornados, draught, temperature extremes)	Injury-resistant architecture	Socioeconomic status of individuals and groups
Exposure to infectious pathogens (e.g., viruses, bacteria)	Psychological hardiness	Alcohol consumption	Ground-water contamination	Nontoxic construction materials in buildings	Social support vs. social isolation or social conflict; bereavement
Immunologic competence	Self-esteem	Smoking	Radon contamination of soil	Ergonomic design of work areas and other environmental settings	Social climate in families, organizations, and institutions
Inoculation and medication history	Creativity	Exercise patterns	Ultraviolet radiation	Environmental aesthetics	Modeling and conformity processes
Congenital disability	Optimisim	Sleep patterns	Atmospheric ozone depletion	Indoor and outdoor air pollution (e.g., "sick building syndrome")	Cultural and religious beliefs and practices
Disabling injuries	Pessimistic explanatory style	Safety practices (e.g., use of vehicular safety belts, bicycle helmets; safe sexual and prenatal behaviors)	Global warming	Effective design of health care facilities	Organizational or political instability
Cardiovascular reactivity	Health locus of control	Participation in health promotion programs	Health consequences of reduced biodiversity	Vehicular and passenger safety	Economic changes (job loss and related stressful life events)
Chronological age	Interpersonal skills	Compliance with prescribed medical regimens	Restorative potential of wilderness and other natural environments	Noise pollution	Health communications and media
Developmental stage	Extroversion	Use of community health services and resources		Electromagnetic radiation	Health promotion programs in organizations and communities (e.g., health education)
Gender	Coronary-prone (Type A) orientation	Health-relevant decisions and actions made on behalf of others		Water quality and treatment systems	Health-promotive legislation
	Cancer-prone (Type C) orientation			Solid waste treatment and sanitation systems	Environmentally protective regulations
	Depression/anxiety				Availability of health insurance and community health services
	Hostility/ suspiciousness				

Figure 1. The SE model from Stokols (1992)

The model developed by Schulz & Northridge (2004) is among the most well-known models (Figure 2). This concept was created with a focus on health and considers how social and environmental factors impact health. But it aids in understanding the rationale behind the elements covered in this thesis and how urban environments affect health. Macro, meso (community level), micro (interpersonal level), and individual or population level characteristics were all explored by Schulz &

Northridge (2004). In contrast to Stokols (1992) 's approach, the linkages between components and how the factors can affect health are discussed. This model also enables us to draw the conclusion that protective measures for urban residents should be coordinated at all levels (individual, local, and national), particularly in the case of air pollution, over which the general public has no control over the quality of the air they breathe. If the model is explained with this thesis topic, there is a reciprocal effect between the macro-level natural environment and the meso-level building environment which has an effect on causing environmental toxins and induces respiratory health problems, such as asthma. The components discussed in this thesis are represented in the model with a red frame.

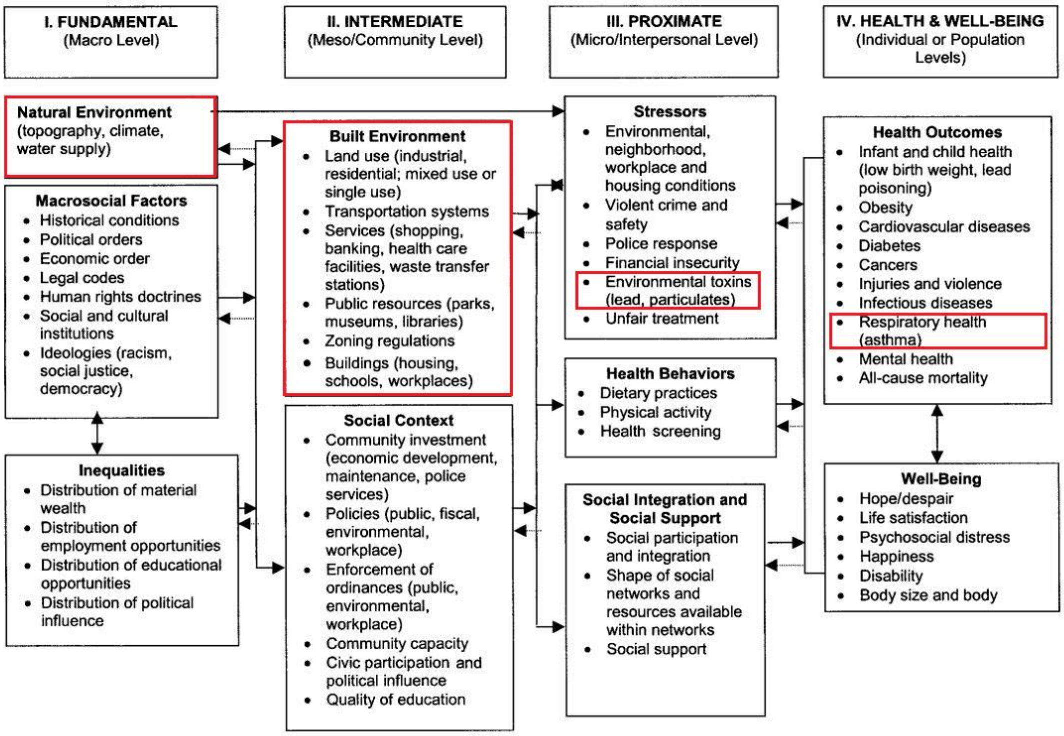


Figure 2. The SE model from Schulz & Northridge (2004)

Sallis et al. (2006) defines a more complex S.E. model that deals with natural environment, sociocultural environment and information environment in terms of different characteristics. This is a broad, multilevel and complicated model that explains different scales, behaviors, environments and policies related to these factors (see Figure 3). Intrapersonal variables showed at the center represents individuals. Perceived environment represents the thoughts of individuals about their environment. Behavior represents the interaction between individual and the environment. Behavior settings are the places where physical activity may occur, and lastly policy environments are the policies, incentives that can be proposed (Sallis et al., 2006). Similar to Stokols' (1992) model, Sallis et al.'s (2006) S.E. model addresses socio-ecological factors that may have an impact on health without addressing how or to what extent these factors affect health. A red line indicates the factors that are addressed and discussed in this thesis.

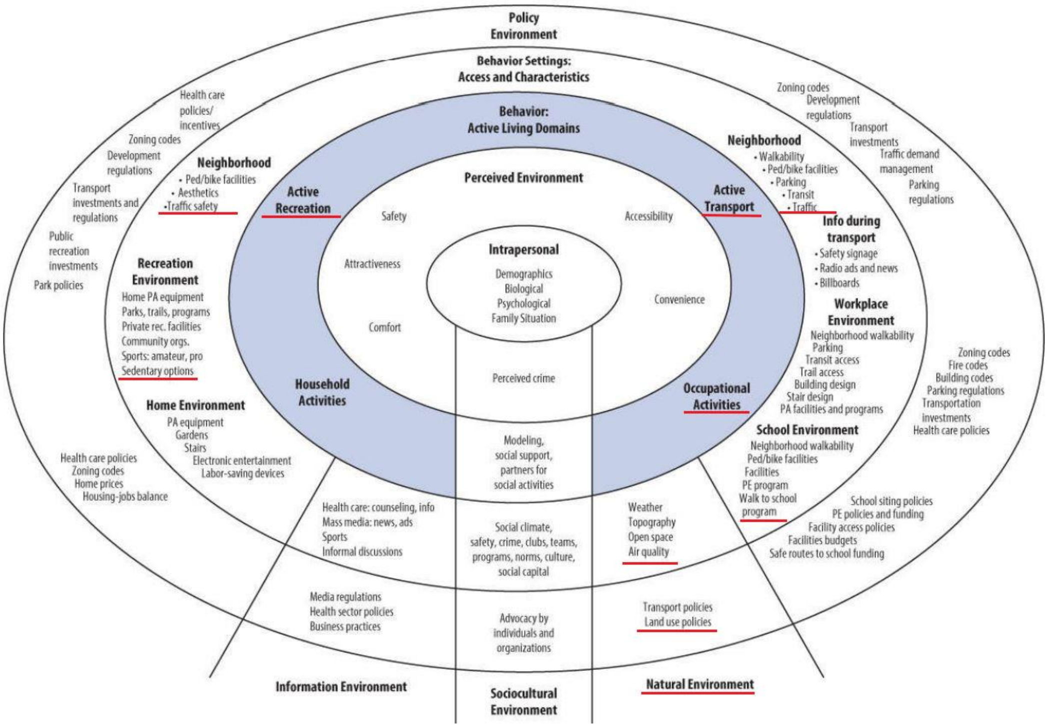


Figure 3. The SE model from Sallis et al. (2006)

Finally, Rydin et al. (2012) 's model was examined within the scope of this thesis. The model highlights the role of the urban environment in affecting the public health. Here, it is important to note that this model is not a S.E. model. Furthermore, it did not follow a scale-based approach. Rydin et al. (2012) took the city-scale as a basis and dealt with the relations of the factors of this scale with each other. If we explain the components of this thesis based on this model, buildings and infrastructure are affected by morphology and landuse, morphology and landuse affects urban climate which has an impact on air quality. Also buildings and infrastructure have affects on transport and quality of urban environment. Transport has an affect on air quality and lastly, air quality is one of the causes of chronic diseases. Figure 4 illustrates Rydin et al.'s (2012) model. The topics that are addressed in this thesis are highlighted with a red frame.

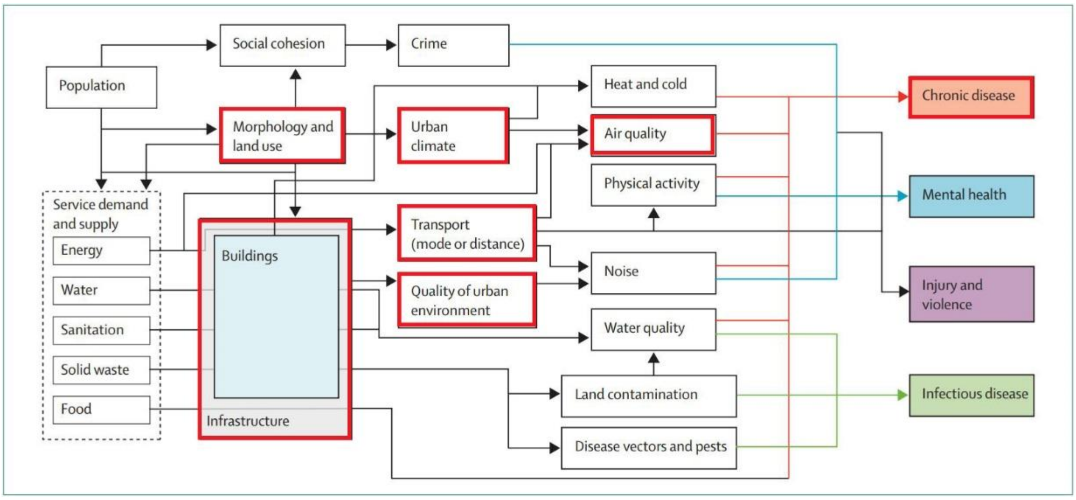


Figure 4. Health outcomes and the urban environment (Rydin et al., 2012)

All of the abovementioned models emphsasize the role of city planning in public health. The city planning discipline deals with a variety of issues such as the site selection of land uses, things that should be taken into account in urban design processes (like building heights), how different land uses should be linked to each other, and so on. In fact, analyzed from a historical point of view, public health concerns led to the development of planning. The emergence of the urban planning discipline was motivated by the desire to ease congestion, boost the general public's health, and encourage social transformation in housing and sanitation. The focus on urban reform and the shared objective of preventing infectious disease outbreaks through infrastructure improvements, which is a highly effective strategy to improve population health, united the planning and public health professions. However, the professions started to diverge over time. Planners prioritized land use and transportation above addressing health and safety issues. On the other hand, public health experts took the lead in addressing health and safety issues (ARHF & ARC, 2006).

City planning and public health professions share common roots. Historically, many major planning initiatives grew out of health-related concerns. Haussmann's radical plans for Paris in the 1850s were intended to improve airflow and abate unhealthy sanitary conditions (Saalman, 1971). The state of a city's inhabitants to live long, healthy, and productive lives can be significantly impacted by the planning methods used to build that city. The design of streets and corridors, as well as the land-uses that they connect, are influenced by planning. City planning decides on the direction of the growth of the city and establishes the locations of the city's main components, including public parks, business areas, hospitals, cultural areas, commercial areas and schools. Each city is unique because of the way these elements interact, which are reflected in its various neighborhoods, streets, and transportation hubs. The presence or absence of these elements has an impact on both the health and quality of life of urban dwellers. While attempting to construct a location where people can live and prosper, city planning aims to alleviate the negative impacts of living in urban areas on the health of their residents. The city should provide access and opportunities that help people lead healthy lives.

Public health experts and city planners shouldn't work in isolation as community health issues increasingly revolve on chronic disease and safety. Local air quality, water quality and supply, traffic safety, physical activity, mental health, social relationships, and exposure to toxic industrial sites have all been impacted by decisions made by policy makers regarding land use, community design, and transportation. These choices are associated with some of the most challenging issues in public health, such as adult and pediatric obesity, cancer, respiratory problems, inactivity, and environmental justice (APA, 2012).

2.2 The Link Between Urban Environment and Outdoor Air Pollution

It has long been recognized that the natural and physical environment of urban areas has a significant impact on poor air quality (Akilan & Nandhakumar, 2016; Stone et al., 2007; J. Yang & Zhang, 2018). Measuring and characterizing how and to what degree particular aspects of the urban environment affect air quality in cities is an important step for city planners and designers. The city's coordinates, geographical and climatic characteristics significantly affect the air quality of the city, as seen in all S.E. models examined within the scope of the thesis. The literature has been reviewed for those who have studied the natural environmental characteristics of the city and the effect of these features on the air quality.

According to the literature, places at higher altitudes have more air flow, which results in less PM10 and PM2.5 concentrations (Ning et al., 2018). Also, in a street-scale research that assessed air pollutant concentrations at 0 m and 35 m heights of the same spot on rainy and non-rainy days, it was discovered that measurements obtained at 35 m had lower concentrations under all circumstances (Warlina et al., 2019). However, there are also urban areas with high pollution, although they are located at geographically high points, mainly due to wood burning to heat residents (Dimitriou & Kassomenos, 2018).

The temperature is associated with PM10 concentrations and cause-specific mortality (S. Kim et al., 2015). It has been established that rising temperatures and humidity negatively impact the air quality in cities (Leung & Gustafson Jr., 2005). Gases emitted into the air from different sources such as vehicles, industry, and residences become challenging to leave the environment due to the increase in volume with the hot air and intense humidity in the environment. Thus, any urban intervention that increases heat absorption-release (such as expanding concrete-covered large vehicle parking spaces or shrinking urban green spaces) will raise the urban environment's temperature and lower air quality (Jayamurugan et al., 2013; Leung & Gustafson Jr., 2005). Another study determined that traffic-related air pollution is higher in regions with low wind speeds (Elminir, 2005).

The built environment variables, in addition to the natural environmental components, significantly impact the city's air quality. When we look at the literature about figure-ground analysis and air pollution, there is a study that uses solid and void areas to simulate airflow (Sarı & Aybek, 2018).

It has been proven that the number of floors of the buildings affects the wind direction and speed (J. Yang et al., 2020), thus causing the formation of urban heat islands (Liang et al., 2021) and affecting the air quality.

Green area and air quality connections in the literature were made using NDVI (Normalized Difference Vegetation Index) calculated from satellite images (Gajjar et al., 2021; Zhan et al., 2018). NDVI is formulated based on the colors reflected from the earth to the satellite. Although an applied field study on the impact of green spaces on air quality in cities has not yet been done (McCarty & Kaza, 2015), studies using images from satellite images and data from air quality monitoring stations have shown that enclosing forested areas improves the air quality in urban environments (Escobedo & Nowak, 2009; McCarty & Kaza, 2015; Zipperer et al., 1997). Also, computer simulations demonstrate that adding green spaces like parks, gardens, and green roofs improve air quality (Tallis et al., 2011). While green areas improve air quality, industrial areas cause air pollution that adversely affects human health. This relationship has been identified by various studies in the literature (Morin et al., 2012; Pope, 1989).

The literature about street connectivity and air quality is mainly handled by focusing on walkability and compactness of areas. It has been discovered in the literature that a high pedestrian density is correlated with high connectivity rates (Hajrasouliha & Yin, 2015). Some of the studies in the literature also emphasize that land-use mix ratios should be taken into account along with connectivity when assessing walkability. The literature on this subject has proven that as walkability increases, air pollutant concentration decreases (Forsyth & Southworth, 2008; Marshall et al., 2009; Moudon et al., 2006). Frank et al. (2007) determined that increasing the walkability index (measured by changes in urban form elements such as increasing land use diversity and building density) of a neighborhood by 5% enables each person to travel 32.1% more actively (walk or bike more when getting from one point to another), travel 6.5% fewer kilometers by car, and thus there is 5.6% less nitrous oxide and 5.5% less volatile organic matter into the air. This study shows that urban planning and design practices affect the outdoor air quality in neighborhoods by influencing the urban form.

Traffic is one of the most studied fields in terms of air pollution. There are a lot of studies that investigate traffic's role in air pollution and connect this issue to public health (J. J. Kim et al., 2004; Nordling et al., 2008; Soegoto et al., 2019; Zhou & Levy, 2008). Street patterns that prevent wind flow and cause exhaust emissions undoubtedly pose a severe threat to the health of children who actively use the street. In addition, air pollution remains in the street because of the form of urban neighborhoods (e.g., building form, building density) and other physical environmental factors (such as the presence of large amounts of paved surfaces) that prevent airflow and cause heat islands. Spending time in a street environment, especially after school and in the evening when vehicle traffic is at its busiest, exposes children more to the side effects of air pollution (Graham, 2004).

Studies on the impacts of meso-scale urban form factors (such as the solid void ratio, the height of buildings facing the street, different uses of buildings on the same street, street level amount of green areas) on the environment's air quality are still limited in the literature that we are aware of. The primary cause of this, according to Borrego et al. (2006), is the difficulty of numerical measurements and the inconvenience of the spatial analysis's indicators. There are a few studies focusing on street level air pollution and searching for the reasons of this pollution in terms of land-use and building density (Liu et al., 2021), different socio-economic status (Dionisio et al., 2010), and urban park and traffic (Bouhamra & Abdul-Wahab, 1999; Qu et al., 2019). Since the literature examining the connection between urban environment and air quality at this scale, using the data gathered from the street, pointwise, is still in its infancy, city planners and designers have only a limited understanding of this link. There is a theoretical report about street-level air pollution (Spirn, 1986). According to Spirn (1986), the street is the busiest outdoor open space in the city where people live and work and spend much of their time driving, walking, sitting, and playing outdoors. Unfortunately, the street is also the source of much of the city's air pollution. The degree to which pollutants emitted at the street level is concentrated or dispersed is greatly affected by the form of the city. Urban design, especially if integrated with other measures, could play an important role in dispersing street-level air pollutants. At the very least, urban design can help in limiting human exposure in areas where pollutants are highly concentrated. In Spirn's (1986) theoretical study; the application of effective urban design measures to reduce exposure to street-level air pollution depends on an understanding of these factors, both individually and in combination: Emission levels, proximity to the roadway, air circulation winds, and breezes, air circulation-inversions, air circulation-spatial confinement, sinks, pollution sensitive users and activities.

The relationship between the urban environment and air quality at the city scale (in the city as a whole), however, is a topic covered in a number of studies in the urban planning literature (Bechle et al., 2015; Bereitschaft & Debbage, 2013; Lu & Liu, 2016; McCarty & Kaza, 2015; Yuan et al., 2018). Most of these studies have correlated urban environment and air quality at the city scale using two main data sources: (1) satellite images depicting air pollution and (2) data from city air quality monitoring sites (data from stations applied to the city as a whole). They have revealed that various urban environment characteristics are associated with cleaner/less polluted air. There also conflicting results. The primary causes of this include the city's geography, climate, various land uses (particularly the presence of heavy industry), street layout, traffic density, fuel type used in cars, wind direction in the city, building position, and a network of many other macro, meso, and micro-scale variables that affect the city's air quality. The main questions in this thesis originated from the observation that the majority of existing empirical studies are based on city comparisons and very limited number of studies has investigated the relationship between different urban environment features and air quality in street level.

Studies that have compared the compactness of cities with their air quality have discovered that, in general, elements that allow for compact (non-fringed) construction, like building density and land use diversity, have an impact on the air pollution levels of cities (Bechle et al., 2011; Frank et al., 2000; Johnston & Ceerla, 1995; McCarty & Kaza, 2015; Stone & Rodgers, 2001; Y. Zhang & Gu, 2013).However, contradictory findings also exist in such studies. For instance, Bechle et al. (2011), by using data obtained from satellite images, found that cities with moderate to highly crowded, compact, and high land use diversity had higher air quality than those with less dense, fringed (non-compact), and sparse land use. Similar findings were obtained by McCarty and Kaza (2015), who discovered that the urban environment's fragmentation makes the city's outer suburbs' air quality poorer. The researchers' general interpretation of these findings is that people prefer to walk more in cities where different land uses, such as homes, workplaces, schools, parks, and markets, are closely spaced out from one another. This results in better air quality than widespread and fringed areas, which encourages the use of vehicles. There are also scholars who have determined that planning practices that increase physical activity, such as increasing building density and in-fill development, increase air pollution. For example, Stone and Rodgers (2001) and Zhang and Gu (2013) found that denser and more compact cities have more building surfaces, resulting in increased heat absorption. They found that pollutants such as carbon monoxide (C.O.) and particulate matter (PM) cause them to hang in the air, which causes more harmful pollutants to be inhaled while walking on the street.

According to Clark et al. (2011), the urban form variables with the strongest statistical power for predicting air pollution concentrations are population centrality (correlated with lower concentrations) and population density (correlated with higher concentrations); other urban form variables that influence the air quality directly and indirectly are travel behavior, land cover, and spatial distributions of land use.

All in all, a review of the literature shows that, the majority of research aimed at investigating the relationships between urban environment and air quality have employed satellite imagery or used data from city air quality measurement stations.

There is limited research on the factors affecting outdoor air quality at the street-scale. For example, Bouhamra & Abdul-Wahab (1999) randomly drove around the streets of a residential area in Kuwait with a mobile air measurement device and found that the areas with the worst air quality were the streets with heavy traffic. The same study added that construction sites adversely affect the air quality mainly due to large trucks using diesel fuel entering and leaving the construction sites. In a different research on street scale, Liu et al. (2021) used a mobile air monitoring system to cycle in the center of Wuhan for four days while collecting data. As a result, they provided specific recommendations on how to implement building standards to lower pollution concentrations in this area.

2.3 The Link Between Outdoor Air Pollution and Childhood Asthma

Outdoor air pollution is a crucial problem in urban environments and one of the primary environmental risks that children are exposed to. Several research on mortality and morbidity associated with urban air pollution found that children would be more susceptible to air pollution than the general population (Bates, 1995; Penna & Duchiade, 1991).

Urban air quality studies have shown that some gases and particles negatively impact human health. Urban air pollution can penetrate the bloodstream and affect all organ systems. The impacts of air pollution can be either transitory (e.g., coughing) or long-term and irreversible, ranging from cardiovascular and respiratory disease, lung and other cancers, asthma and other non-communicable diseases (NCDs), poor birth outcomes, and developmental challenges. It’s proven that there is a positive association between the risk of childhood asthma and ambient air pollution (Olaniyan et al., 2015). Air pollution, and in particular its fine particulate component, has been classified as a cause of lung cancer (IARC, 2013). According to the World Health Organization (WHO, 2018), air pollution (both indoor and outdoor) is linked to 7 million premature deaths annually and a substantial reduction in years of healthy life. Over the past few decades, allergic disorders have become much more common, particularly in children and young adults (Pawankar, 2014). The dynamics of this occurrence indicate that it is the effect of changes in the environment rather than the influence of personal factors like age, gender, heredity, and so on.

Asthma is known as reversible or partially reversible blockage of airways. It appears as episodes of wheezing, coughing, and shortness of breath that can range in severity (Maddox & Schwartz, 2002). Globally, more than 339 million people are asthmatic (Global Asthma Network, 2018). Research strongly suggests that asthma in children could be significantly decreased by reducing environmental asthma triggers such as allergens and air pollutants. For instance, Friedman et al. (2001) examined whether asthma incidents decreased during the 1996 Olympic games in Atlanta, Georgia, when Atlanta implemented a plan to lessen traffic by encouraging the use of public transit on a large scale. These efforts resulted in a 22% decrease in traffic counts, a 28% decrease in daily ozone concentrations, and most importantly, a 41% decrease in asthma acute-care events.

Many urban land uses affect outdoor air quality. Nevertheless, heavy industries, petrochemical plants, oil refineries and mining areas are some of the most polluting. A variety of volatile substances and particulate matter are released into the atmosphere by petrochemical plants, heavy industry, and oil refineries. Numerous studies have shown a connection between childhood asthma symptoms and living near petrochemical and industrial facilities (Pope, 1989; Rovira et al., 2014; Rusconi et al., 2011; Ware et al., 1993; C. Y. Yang et al., 1998).

2.4 The Link Between Urban Environment and Childhood Asthma

Existing research shows that children living in the city are more likely to have asthma than those living in the urban periphery, where construction and vehicle traffic is less frequent (Crain et al., 1994). Many disciplines have conducted and continue to examine the relationship between the urban environment and childhood asthma (medicine, environmental engineering, public health, etc.). The theoretical thrust behind the direct relationship between physical environments of urban areas and outdoor air pollution and outdoor air pollution and childhood asthma is undeniable, but the indirect relationship between the urban environment and childhood asthma and its particular aspects, including mechanisms and weight of particular urban physical characteristics (altitude, geolocation, land-use, the density of buildings and green, street types, connectivity, etc.), have been inadequately explored.

Urban environment, as is used in this thesis, refers to the physical (natural and built) characteristics of urban areas (geolocation, climatic feature, land use, the density of buildings and green, street types, connectivity, etc.). Within the scope of this study, the literature is divided into four different titles based on urban environmental factors associated with childhood asthma. These titles are: Urban-Rural Differences (URD) and Childhood Asthma; Traffic-Related Air Pollution (TRAP) and Childhood Asthma; URD, TRAP and Childhood Asthma; and lastly, Urban Environment Related Air Pollution (URAP) and Childhood Asthma.

2.4.1 Urban-Rural Differences (URD) and Childhood Asthma

This section reviews the literature that have examined the effects of living in urban and rural areas on childhood asthma. Past research studies have compared urban and rural structures, even though they did not expressly address the physical characteristics of urban environments. This helps us understand how cities that are growingly car-dependent, congested, and removed from nature affect childhood asthma. After a careful review of hundreds of publications that show up on web search engines, ten research articles were reviewed. Six of these studies demonstrated that compared to urban environments with plenty of traffic and buildings, rural areas are healthier for children with asthma. One of these studies (Renzetti et al., 2009) conducted a real-life experiment; the authors took 37 urban asthmatic children on a field trip to a rural region, where the changes in asthma symptoms were analyzed. They discovered that better air quality in rural areas is linked to a rapid reduction in airway inflammation in allergic asthmatic children.

In 8 of the studies, there were no air quality measurements. Only two studies examined the level of air quality derived from stationary data (Ranzi et al., 2004; Renzetti et al., 2009). Among these, Renzetti et al. (2009) used stationary data for the metropolitan region and a mobile station to measure the air quality in the rural areas.

Four investigations did not find a correlation between urbanization and childhood asthma. Pesek et al. (2010) found that while asthma prevalence is similar in urban and rural areas, morbidity is significantly higher in rural areas. However, as the authors noted in their discussion of the study's limitations, they did not question the environmental triggers and exposure to farm and indoor animals. In another study that was conducted in Cyprus, (Kolokotroni et al., (2011) compared survey results that were obtained in two different years, 2000 and 2008, and found that the increases in asthma and allergic rhinitis outcomes were more apparent in rural than in urban areas. However, in the limitations of this study, it was stated that exposure to animals and agricultural practices was not included in the correlation due to the lack of comparable data. Other limitations of this study were that scholars determined the children's addresses during the survey period; prior addresses were unknown and the paper contained no details about the pollen season's status. In Nystad et al. (1997)'s study, although the findings do not support the theory that respiratory illness is more prevalent in urban regions than in rural areas, they did discover that the lifetime prevalence of asthma is higher in urban areas than in rural ones. Additionally, as the authors of the article mentioned, they carried out the survey in rural areas in May during the pollen season. They also did not address domestic or farm animals. Lastly, in the SIDRIA (1997) study, based on data obtained from questionnaires, the researchers found that urbanization was associated with chronic airway irritation rather than with asthma. However, when they used doctor-diagnosed asthma rates, they found a direct correlation between urbanization and childhood asthma. Although the pollen season was considered in the study, the authors failed to discuss exposure to pets, farm animals, and farming activities.

Among the ten studies that were reviewed for the purpose of this section, none of the studies (except Forastiere et al., 1992) stated the type of fuel or the heating strategy used to heat the home. Particularly in rural regions, sources of domestic heating may be a significant factor in childhood asthma.

Since asthma can emerge or be triggered for a variety of reasons, when we look at studies on URD and childhood asthma in general, we see that there are various factors that affect childhood asthma both in rural and urban areas. In some studies, (e.g., Odhiambo et al., 1998), although children in rural areas are exposed to more triggers, urban areas have been found to be more likely to affect asthma, while other studies have concluded that the prevalence of asthma is higher in rural areas. In these studies, we observe that researchers either conducted the questionnaires during pollen season or they did not ask any questions related to exposure to agricultural activities, domestic and farm animals.

When all of these elements are considered, it is possible to claim that urbanization and the air pollution it produces are directly associated to childhood asthma (the pollen season, agricultural activities, and exposure to domestic animals are eliminated).

2.4.2 Traffic-Related Air Pollution (TRAP) and Childhood Asthma

The studies discussed here deal with how traffic-related air pollution affects childhood asthma. Although traffic is not a physical urban form characteristic, it emerges as a result of the structuring of cities that grow planned or unplanned. During the lockdown period of the pandemic, when people were completely confined to their homes, several studies were conducted in different countries to examine how air pollution in cities changed since the pre-pandemic times (Aydın & Yetişkul, 2021; Kumari & Toshniwal, 2020; Nakada & Urban, 2020). These studies have shown that air quality in cities improves, and concentrations of some atmospheric pollutants decrease when urban residents do not rely on motorized transportation for travel. TRAP has been regarded as an environmental co-factor, and it aids in our comprehension of how traffic that drove by urbanization impacts childhood asthma.

Under this title, 21 research articles on TRAP and childhood asthma were evaluated. When the studies are looked at collectively, we find that seven of them don't use air pollution data, three use stationary data, three use models, and four get their data through passive sampling. When looking at health data, we found that 15 of them use questionnaires and six use hospital/health databases. In terms of traffic data, it can be seen that eight of them use traffic volume, six use the distances from homes or schools to major roads, and seven use both data sets.

The research findings on the relationship between TRAP and childhood asthma are contradictory. While 5 of the studies examined under this title did not find a significant correlation between TRAP and childhood asthma, 16 of them found a directly proportional relationship. The author found four studies that explained this contradiction. Additionally, there were four studies that clarified the relationship between TRAP and childhood asthma. These studies and their key findings are as follows:

-In Gasana et al. (2012)'s study, 19 studies were included in the meta-analysis, and it was discovered that children are exposed to higher levels of motor vehicle air pollutants while living or attending school near high traffic density roads, which increases the incidence and prevalence of childhood asthma and wheezing.

-In Favarato et al. (2014)'s study, writers performed a meta-analysis of studies finding links between nitrogen dioxide and the frequency of asthma diagnoses or symptoms across time. They discovered that despite its small size, traffic-related pollution may significantly impact asthma prevalence due to the high baseline incidence in many cities.

-In their review of birth-cohort research on the connection between TRAP and childhood asthma, Bowatte et al. (2015) discovered that exposure to TRAP in early childhood is linked to asthma development in children up to the age of twelve. Age-related increases in these relationships' strength are evident in the pattern for PM2.5.

-In their literature review study, (Han et al., 2021) discovered that exposure to TRAP is a risk factor for childhood asthma and that exposure to NO2, PM2.5, Benzene, and TVOC will increase the prevalence of the disease.

When the research articles and literature review articles examined under this title are considered in general, it can be concluded that there is a direct correlation between TRAP and childhood asthma and that traffic-related pollutants trigger childhood asthma and increase the incidence of asthma, especially if children live in heavy traffic areas.

2.4.3 URD, TRAP and Childhood Asthma

Some research has simultaneously compared the effects of TRAP and URD on childhood asthma. Five research articles were examined under this heading. Two of these studies used stationary data, one measured pollutant ratios using passive sampling, one used station data for PM10 and PM2.5 and a model for NO2, and one study did not use any pollution data at all. While the remaining studies only utilized self-reported questionnaires, two employed hospital databases and questionnaires to collect health information. When the studies' findings were evaluated, three showed that TRAP and URD were directly related to childhood asthma. However, the results of the two other studies were different regarding URD and TRAP.

In their study in South Korea, Hwang et al. (2011) found that although there were no significant differences in the prevalence of self-reported asthma between the two geographical sites, Andong (semi-rural) had a considerably higher rate of physician-diagnosed asthma than Seongbuk (metropolitan area). The authors also revealed that whereas NO2 concentrations were significantly greater in the Seongbuk region, SO2 and O3 concentrations were higher in the Andong region. They established a link between SO2 and O3 and the prevalence of childhood asthma, but the investigation did not reveal whether urban environmental conditions are responsible for the elevated levels of outdoor pollutants. Even though this study makes a significant contribution to the literature, there were several limitations of it. First, it focused on a small urban area and an area in the hinterland of the metropolitan area. Therefore, we cannot talk about the urban-rural comparison in the study. This interpretation leads to the conclusion that, although categorized as semi-rural and metropolitan, both research locations exhibit urban environment characteristics. Second, the traffic data is self-reported; it was collected using a questionnaire. On the other hand, the authors of the study explained the lack of a relationship between traffic data and asthma as being caused by the fact that South Korean cities are very dense and the distance between homes and main roads does not vary significantly. Finally, the fact that the urban components are not considered when evaluating the data prohibits us from viewing this study as an urban-rural comparison.

Altuğ et al. (2014) also found a direct correlation between Ozone concentration and the prevalence of upper respiratory tract complaints (see Figure 5). When the study was thoroughly analyzed, it became clear that the zoning was created, as shown in Figure 2. However, as we can see from the figure, the urban and suburban areas are located in independent geographical areas with different urban features (for example, there is an industry next to an area taken as suburban). Each urban environment has unique characteristics, as well as characteristics that influence outdoor air quality and, consequently, childhood asthma. We cannot understand how the urban environment affects childhood asthma as a result of considering the many locations within the city as a single region.

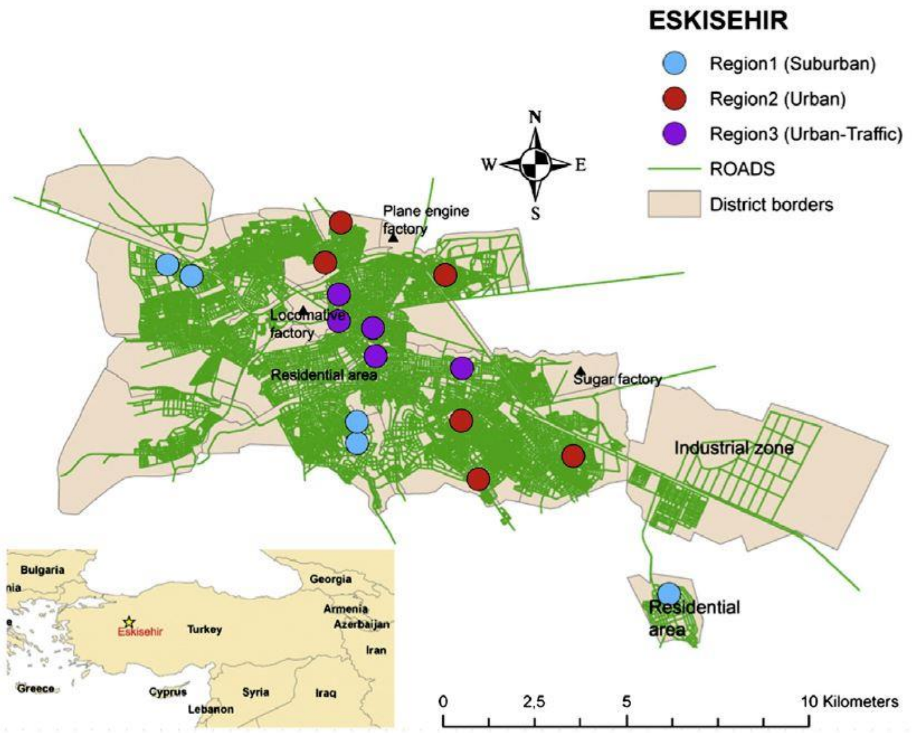


Figure 5. The case areas in Altuğ et al. (2014)'s study

A direct correlation between the quantity of ozone concentration and asthma was discovered in both studies that could not identify a connection between URD-TRAP and childhood asthma, which is crucial for the literature.

2.4.4 Urban Environment Related Air Pollution (URAP) and Childhood Asthma

This section focuses on the studies that investigate one or more physical form characteristics of urban environments and their effects on children's asthma. Six research articles were examined under this heading. While four of the studies did not use air quality measurements, one of them used station data and one of them took measurements within the scope of the study. Four of the studies used the ISAAC questionnaire, whereas two used the hospital database to identify asthma patients (see Appendix B, Table B.6).

Two of the studies examined NDVI as an urban environment variable and examined whether it was associated with childhood asthma. One study (Cavaleiro Rufo et al., 2021)found that living in greener environments reduced the prevalence of asthma in children, while another study (W. Huang et al., 2021) found that NDVI was not shown to modify the risk of pediatric asthma exacerbation. The authors blamed aeroallergens, specifically tree pollens by certain tree species, for this.

In one of the studies (Bobrowska-Korzeniowska et al., 2021), a project is discussed that aims to comprehend how urban heat islands effect air pollution and the ensuing children's respiratory disorders. The project's conclusions were not included in the article under review, although the study of urban heat islands in this context is crucial for the planning field, city planners, and urban designers.

One of the studies dealt with the areas undergoing changes related to urbanization in Ecuador and it was determined that urbanization is directly correlated to the prevalence of asthma (Rodriguez et al., 2011).

One of the studies (Corburn et al., 2006) used Environmental Load Profile (ELP) to determine the factors affecting childhood asthma at the neighborhood unit level. To define ELP, writers used density of air polluting facilities, the density of polluting land uses; manufacturing zone, gas stations, repair garages, power plants, sewage treatment plants, rail yards, and truck routes. As a result of the study, it has been determined that the places where the noxious land-uses are collected coincide with the places with the highest asthma hospitalization rates.

LUM values were utilized as the urban environment variable in the last study (Paciencia et al., 2022) analyzed under this heading, and no relationship was found between LUM values and clinical asthma diagnoses. Although the findings did not show an association between LUM and asthma, the writers found that high land use diversity may have a protective effect on wheezing in the last 12 months among children, and the presence of respiratory symptoms, including wheezing, are hallmarks of asthma.

2.5 Concluding Remarks and Gaps in the Literature

A reviw of the literatature points out that, first of all, the collaboration of public health professionals, environmental engineers and city planners is essential to solve issues related to public health and air pollution. The literature demonstrates that the urban environment characteristics – the density of buildings, traffic density, NDVI, land-use mix, and rural and urban differences etc. – are affect outdoor air pollution and childhood asthma. Although the studies that have examined the connection between the urban environment, outdoor air pollution and childhood asthma are highly helpful for urban planners to respond air quality related health problems, there are many aspects of the urban environment that have not yet been explored but are likely to be related to outdoor air pollution and childhood asthma, especially at the street level (street connectivity, heights of buildings, urban heat islands, street canyons, the presence of green spaces, etc.). The literature approves that the urban environment directly affects outdoor air quality and outdoor air quality directly affects childhood asthma. However, there are still great deficiencies in the literature about the indirect relationship between urban environment and childhood asthma caused by outdoor air pollution. The challenge of adjusting for many variables in an observational setting has been a significant limitation of studies on the effects of urban environments on childhood asthma. The relationship between the urban environment and childhood asthma is a relationship that needs to be addressed at different scales. It is necessary to conduct studies at street scale, neighborhood unit scale, city scale, and regional scale. Studies that compare various physical characteristics of streets, neighborhoods, cities, and regions should also be addressed.

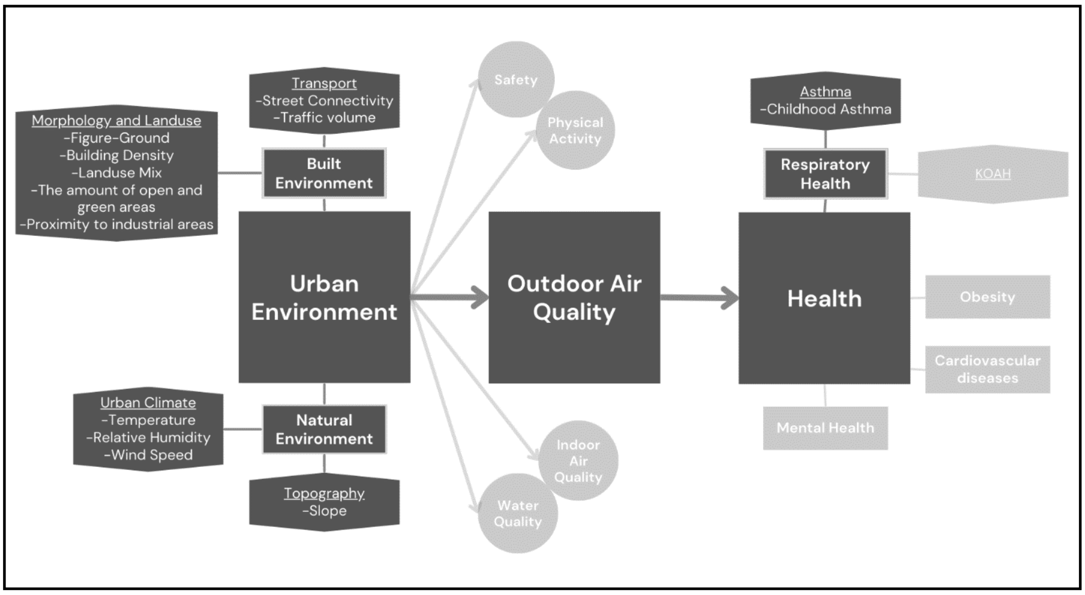


Figure 6. The relation between urban environment, outdoor air quality, and childhood asthma

The model used in this thesis is demonstrated in Figure 6. This model resembles the one developed by Rydin et al. (2012). The model deals with the urban environment's effects on outdoor air quality and health. In more detail, the natural environment and the built environment have been used as urban environment components. Topography (altitude) and meteorology (temperature, relative humidity, and wind speed) are considered as the characteristics of the natural environment, while transport (street connectivity and traffic volume) and morphology and land-use (figure-ground, building density, land-use mix, the amount of open and green areas, and proximity to industrial areas) are considered as the characteristics of the built environment. It is well established that these urban environment characteristics have an impact on safety, physical activity, indoor and outdoor air quality, and water quality. Outdoor air quality, one of the factors impacted by the urban environment, has been discussed within the context of this thesis. It has been tried to determine how the air quality of the regions with various urban environmental characteristics changes, as well as which features have a positive and negative impact on the air quality. Poor outdoor air quality negatively impacts human health, and research has shown that it causes obesity, mental illness, cardiovascular disease, respiratory diseases (asthma, COPD) and obesity. The impact of outdoor air pollution on pediatric asthma, one of the respiratory disorders, is covered in this thesis. The Introduction and Literature Review sections provide a detailed explanation of why childhood is addressed in the study.

This thesis will be the first to examine how children's asthma is affected by changing outdoor air pollution due to variations in urban environments in Turkey. The development of this thesis, which seeks to measure air quality at the street level from the perspective of city planning and design, was significantly influenced by the fact that the majority of empirical studies are based on city comparisons and that, to the best of the author's knowledge, there is no study that has investigated the relationship between different city form features and air quality in Turkey. Additionally, to our knowledge, there hasn't been any applied field research done on how diverse urban environmental factors at the street level affect air quality. This thesis, which deals with the effects of urban environment characteristics on air quality at the street level, aims to fill this gap in the literature.

This thesis also tries to determine the relationship between the urban environment and childhood asthma. Looking from this perspective, when the studies reviewed under the title Urban Environment-Childhood asthma were examined, it was found that 13 articles' authors had a medical affiliation (31%), 12 articles' authors had a medical or public health affiliation (29%), three articles' authors had an environmental affiliation (7%), and the 14 articles' authors were from various disciplines with at least one of the authors that had a medical affiliation. This demonstrates that 93% of the studies on this topic were carried out by researchers, at least one of whom was affiliated with a medicine. It has been noticed that none of the authors of the articles that examined and analyzed numerous aspects of the urban environment and focused on the connection between the urban environment and childhood asthma are from the fields of urban planning or urban design. It is unfortunate that an urban planner or urban designer has not addressed this issue, which is closely tied to the natural and built environments of the city. Urban planners and designers need to do comprehensive research on how the components of the physical urban environment affect childhood asthma, and in this context, it is necessary to establish what policies should be developed in order to create healthier environments. To our knowledge, this study will be the first study conducted by a city planner aiming to investigate the relationships between urban form, air quality, and childhood asthma.

CHAPTER 3

METHOD: MEASURING THE RELATIONSHIP BETWEEN URBAN ENVIRONMENT, OUTDOOR AIR QUALITY AND CHILDHOOD ASTHMA IN ANKARA

This chapter introduces the study's research design, including data collection, processing, and analysis methods. It explains the methodology of the research to respond the research questions posed in this thesis. As stated in the introduction chapter, these questions are as follows: (1) What is the relationship between mesoscale urban environment characteristics and outdoor air quality? More spesifically, which features of the urban environment significantly affect outdoor air quality? And, do urban spots with less or more air pollution show a differentiation based on the urban environment characteristics of their surroundings? (2) Is there a relationship between urban environment-caused outdoor air pollution and childhood asthma? More spesifically, are children diagnosed with asthma living in environments with more intense air pollution? And, (3) What are the physical characteristics of the areas where children are more prone to asthma? Related to this final question, the thesis asked: Which urban environment characteristics play a role in promoting childhood asthma?

3.1 Research Design

In order to respond questions posed in this thesis, this study used a cross-sectional research design and adopted a mixed-methodological approach in data collection. In summary, in the first phase of the study, as part of a TÜBITAK (Türkiye Bilimsel ve Teknoloji Araştırma Kurumu) funded research project (project no. 219K243), the author focused on the Ankara (Turkey) case to collect her data regarding the physical environmental qualities of a number of neighborhoods. This process concluded with the urban form analysis of the selected contexts. In the second step, the author visited the selected neighborhoods to monitor street-level air quality. In the third step, the author approached to the childhood asthma data that she received from the Ministry of Health. Finally, data obtained during these three phases were statistically analyzed in SPSS (see Figure 7).

The research design was influenced by a number of factors. Among these, the COVID-19 pandemic was the most influential one. In the early phases of the research, the author aimed to obtain the data for the children's asthma status by using a survey method. Additionally, outdoor air quality measurements were planned to be based on passive sampling, the locations of which were expected to be based on the data obtained from children to represent the places frequently used by them. Beside that the meteorological characteristics of the examined regions would be taken by using climate meters at street level within the scope of the project. The above mentioned TÜBİTAK project aimed to serve such goals. However, after the iniation of this project and finalization of the neighborhood selection, COVID-19 pandemic took hold in Turkey, which led author to change some of the data collection methods and analysis after the analysis of the urban form variables of the chosen neighborhoods. For instance, instead of obtaining survey data from children's parents regarding the children's asthma status, the author decided to use secondary data. This was a necessary change in research design because of the school lockdowns related to the pandemic in Turkey. Furthermore, while it was possible to fund the passive sampling activity through the project (which is a cost-intensive air quality measurement method), the project was paused for a long time related to the pandemic. Thus, the author decided to choose more affordable outdoor air quality measurement methods that would yield valid data in a particular time period. Although obtaining this data from the city's air quality monitoring stations was considered, these stations were not located in the chosen neighborhoods. Thus, the author preferred to collect her own data to increase the validity of the findings.

The following sections aim to expian the methods of this study in detail .

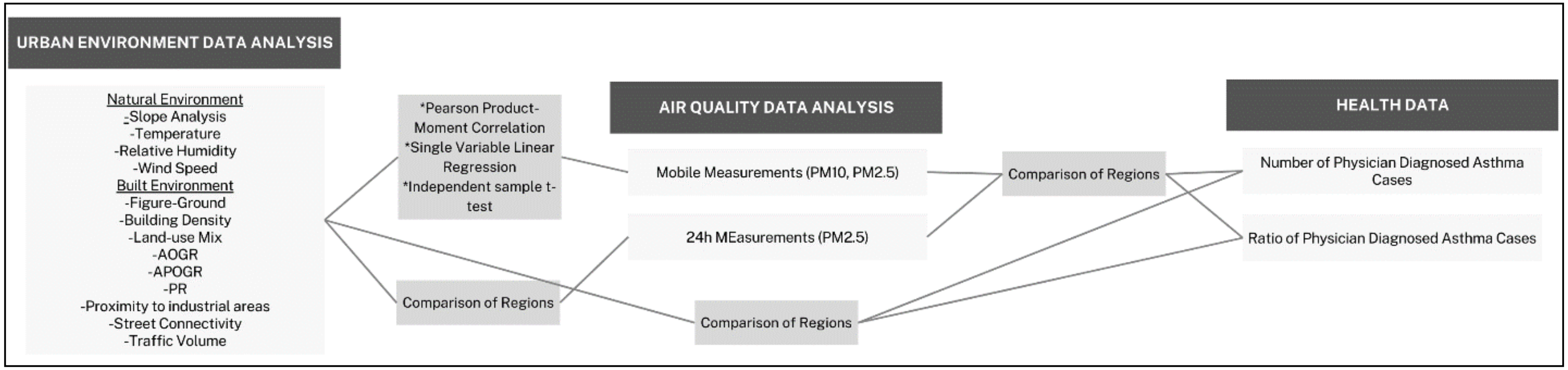


Figure 7. Data Analysis Methods used in thesis (For detailed explanation of the analysis, see 3.4. Data Analysis Chapter)

3.2 Site Selection

The research is focused on the city of Ankara to investigate the relationship between the urban environment, air quality and childhood asthma. Ankara is among the cities in Turkey where asthma and air pollution are seen intensely. Ankara is also a large metropolis with neighborhoods having diverse urban environment charactersitics. Furthermore, considering the number of people diagnosed with asthma in hospitals in 2013 by provinces, it is seen that Ankara is among the nine cities with the highest diagnosis of asthma cases (Al & Özcebe, 2017) A survey conducted in Ankara shows that the prevalence of asthma in primary school children was %8,3 in 1992 and %9,8 in 1997 (Kalyoncu et al., 1994, 1999). According to the Chamber of Environmental Engineering's 2018 air pollution report, Ankara is one of the Turkish cities with the highest levels of outdoor air pollutants, including PM2.5, PM10, NO2, and NOX. These findings make Ankara an ideal case to investigate the characteristics of the urban environment, air quality and childhood asthma.

Following the foundation of the Turkish Republic in 1923, after the declaration of Ankara as the capital city of Turkey, the city started to be developed in a planned way to symbolize the modernization of the country (for the planning history of Ankara, please see, for example, Cengizkan (2003), Keleş (2018), Şenyapılı (2006). However, due to the intense wave of immigration, the planned areas eventually could not meet the needs of the population, causing the emergence of planned urban areas one the one hand, and unplanned, spontaneously developed areas on the other. Ankara is now a metropolitan city with a population of 5,747,325 as of 2021 (TÜİK, 2022) and an area of 2,600,000 hectares (ABB, 2022). Since this thesis aims to understand the relationship between urban environment, air quality and childhood asthma from a mesoscale perspective, and because of the large size of the city, a number of neighborhood units with different urban environmental characteristics were selected from Ankara. Three factors affected the selection of the neighborhoods. The first criterion was the urban environment characteristics of neighborhoods. The site selection was made according to neighborhoods' mesoscale urban environment characteristics. The sites were chosen in accordance with the available data, utilizing all available online map databases, considering the key elements of the urban environment and the various urban zones. Detailed city form analyses were made after the areas were selected, not during the site selection process. The outcomes of the literature review on the connection between the urban environment, outdoor air quality and childhood asthma served as the second criterion. In other words, when deciding on the neighborhoods, the author particularly focused on the urban environmental characteristics that were mentioned in the childhood asthma and outdoor airqulity literature.

This study focused on the asthmic status of children in 7-12 age-range. This range was determined based on the characteristics of the available data. Since this thesis relied on secondary data obtained from the Ministry of Health (to understand the level of childhood asthma in particular geographies), and since the Ministry of Health's data separated the children into two age groups – children in 0–6 and 7–12 age group – it was important for the author to maximize the representation of children in the selected age group, that is 7-to-12 year-old children. Thus, the presence of elementary and secondary public schools in the chosen study areas was the third and last criterion. The geographic extent of the neighborhoods is defined by creating buffers around the public primary and secondary schools in the neighborhoods. In Turkey, children are automatically placed in public schools, depending on the address where they are registered/lived (according to the 11th article of the Ministry of National Education Pre-School Education and Primary Education Institutions Regulation, "Registration is done through the e-school system, based on the address information in the national address database"). Finally, neighborhoods with more than one school were preferred over neighborhoods with only one school.

In line with all these criteria, a total of 8 neighborhoods were selected, 4 of which are from the inner city and four from the periphery (Figure 8).

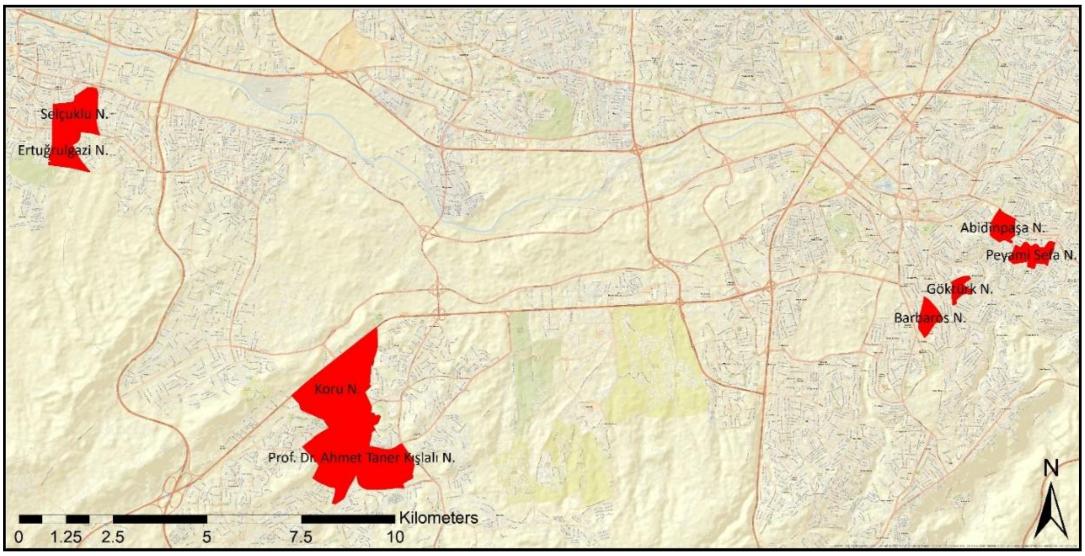


Figure 8. Selected neighborhoods from Ankara Metropolitan Area

The first two neighborhoods selected from the urban periphery are Koru Neighborhood and Ahmet Taner Kışlalı Neighborhood from the Çankaya district. Both neighborhoods have one primary and one secondary school within their administrative boundaries (please see Figure 4 for the location of these schools on the satellite maps of the chosen neighborhoods). Large open green areas surround these neighborhoods. As can be clearly seen from the satellite images shown in Figure 4, these neighborhoods have more green areas than the other chosen neighborhoods. Although street connectivity seems to differ from one point of the neighborhood to another (for example, areas with grid-patterned housing and site-type housing with a more curved street structure), it is understood from the examination of satellite images that street connectivity in Koru and Ahmet Taner Kışlalı neighborhoods is relatively low in terms of average values compared to the chosen neighborhoods close to the city center. Compared to the chosen neighborhoods close to the city center, they have larger building blocks. Them seem to have a lower building density and a lower land use diversity (housing intensive) than other selected neighborhoods. Both selected neighborhoods are far from industrial areas. In these neighborhoods, in addition to seeing high-rise housing surrounded by parking lots, we also see two- and three-story housing surrounded by gardens. We can see attached and detached housing types in Koru and Ahmet Taner Kışlalı neighborhoods. In some parts of these neighborhoods, we can see three-story buildings, five-story buildings, and ten-story buildings side by side.

The other two neighborhoods selected from the city periphery are Selçuklu Neighborhood and Ertuğrul Gazi Neighborhood from Sincan District. Each neighborhood has one primary and two secondary schools within its boundary. Both of these neighborhoods are densely structured neighborhoods. Thus, they do not represent the characteristics of peripheral neighborhoods that can be seen in some other countries like the United States, where building density usually decreases as one moves from the inner-city to the periphery. Ertuğrul Gazi Neighborhood is bordered by Ankara's large undeveloped lands. It includes buildings that are not seen or rarely seen in other selected neighborhoods (for example, 4-5 story buildings arranged around green areas with inner courtyards and mass housing estates surrounded by large green areas). Both neighborhoods seem to have less green spaces comprared to what Koru and Ahmet Taner Kışlalı neighborhoods have (Figure 9). Satellite images further show that the greenness index of the two neighborhoods may vary from Selçuklu Neighborhood to Ertuğrul Gazi Neighborhood (or even from one part of the district to another). These two neighborhoods generally have small block sizes and seem to have less land use diversity than the chosen neighborhoods from the inner-city. Another characteristic that distinguishes these neighborhoods selected in the Sincan District from other districts is the Ankara Organized Industrial Zone, which is approximately 4 km away from the selected neighborhoods.

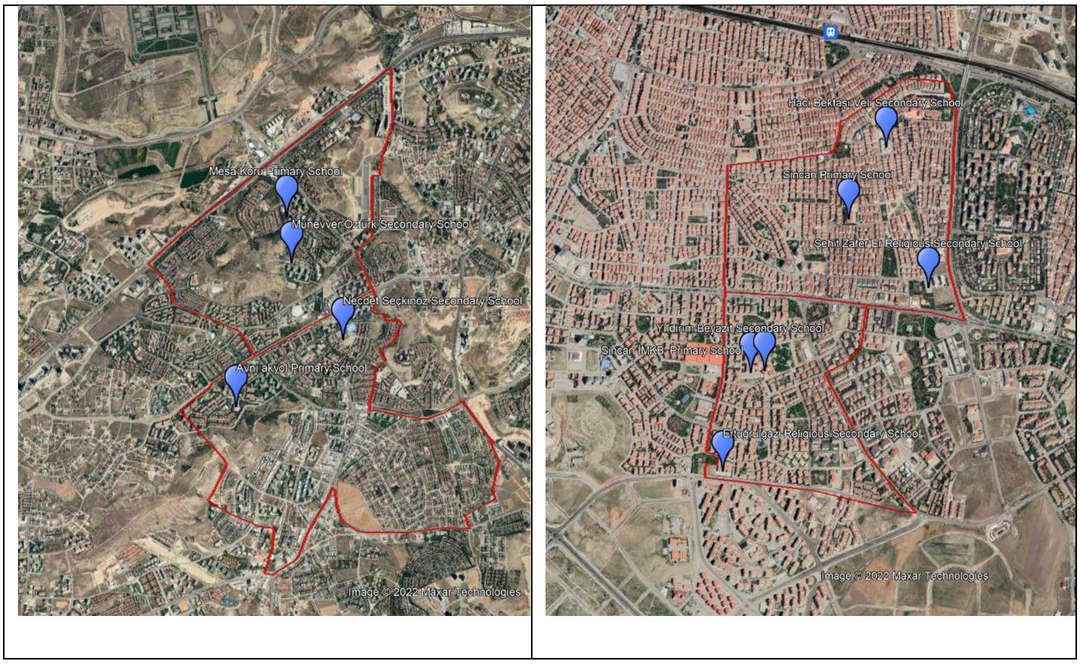


Figure 9. Satallite images of Koru and Ahmet Taner Kışlalı neighborhoods (on Left) and Selçuklu and Ertuğrul Gazi neighborhoods (on Right). Red lines indicate the administrative boundaries of the chosen neighborhoods. Blue markers indicate the loctions of the public primary and secondry schools in the chosen neighborhoods.

The first two neighborhoods selected from the inner-city are Barbaros Neighborhood and Göktürk Neighborhood from the Çankaya district. Barbaros neighborhood has one primary and one secondary school, and the Göktürk neighborhood has one secondary school within its boundary and one secondary school just outside its boundary. Although, in general, the author preferred not to select any schools that are located outside the administrative boundaries of any neighborhood, in Göktürk, the author decided to ignore this rule since the chosen seconday school is located extremely close to the administrative boundary of this neighborhood (i.e., while the chosen primary school is located approximately 50 meters inside, the secondary schools is located approximately 50 meters outside the administrative boundary of Göktürk neighborhood). The selected neighborhoods from Çankaya inner-city have higher building densities compared to the peripheral neighborhoods. As the street patterns are mostly grid-patterned in both neighborhoods, it is seen that they have high street connectivity. In some neighborhoods, the buildings are used as offices, they contain art galleries, and there are commercial areas under the residences; therefore, it is understood that it has a higher land use diversity than the neighborhoods selected from the periphery. These two selected neighborhoods run parallel to Ankara’s green space system from north to south. In the west of these neighborhoods, green areas cover large areas such as Kuğulu Park, consulate gardens, and Seğmenler Park. The main reasons for choosing these neighborhoods are that they seem to be very densely textured, the diversity of land use and building density seem to be much higher compared to the other chosen neighborhoods, and they are close to large forested areas (Figure10).

Figure 10. Satallite images of Barbaros and Göktürk neighborhoods (on Left) and Abidinpaşa and Peyami Safa neighborhoods (on Right).

The last two neighborhoods that were selected from the inner-city are Abidinpaşa Neighborhood and Peyami Safa Neighborhood from the Mamak district. Abidinpaşa neighborhood has two primary schools, and the Peyami Safa neighborhood has one primary and one secondary school within its administrative boundary. It seems that these two neighborhoods have fewer green areas than all the neighborhoods selected within the scope of the thesis. In addition, it is seen that it has a much more curved street structure and therefore is assumed to have lower street connectivity compared to all the neighborhoods selected within this thesis. It is understood that it seems to have a high building density compared to other chosen neighborhoods from the urban periphery. In the context of land use diversity, it is seen that it is on a level between the neighborhoods selected from Sincan and those selected from Çankaya inner-city.

As for the size of the building blocks, it is seen that they are similar to the chosen neighborhoods from the inner city of Çankaya. No large parks or forest areas are near these neighborhoods (Figure 10).

As mentioned above, the geographic extent of the neighborhoods is defined by creating buffers around the public primary and secondary schools in the chosen neighborhoods. There is a total of 18 schools within the selected neighborhoods. Two schools in the Peyami Safa neighborhood and two schools in the Ertuğrul Gazi neighborhood were in the same block - next to each other. Using Netcad software, the schools in selected neighborhoods are marked, and 800 m buffers are created around them (Figure 11). One buffer is created around the schools that are next to each other. In the end, a total of 16 buffers were defined.

Many studies have employed home or school-based buffers to measure the urban form characteristics of children's environments (Wong et al., 2011). Buffer zones, which can be created in different ways, are assumed to better capture the environmental features of a children's neighborhood than the administrative boundaries of such places for several reasons. As stated previously, in Turkey, children are compelled by law to attend schools near their homes. On weekdays children spend most of their time in school. On weekends, in the absence of safe public spaces around children's homes, the schoolyards act as one of the few places where children can safely socialize with their peers (Sancar & Severcan, 2010; Severcan, 2018). In their journey to school, children find the opportunity to explore their neighborhoods, stop by a grocery, play a few minutes in a playground, meet with their classmates next to a landmark, and so on. On the other hand, the administrative boundaries of neighborhoods may consist of many areas children do not visit, or boundaries of neighborhoods may include too few areas that don't cover children's active zone. Hence, children may not acknowledge the unused areas as their "neighborhoods," or they may acknowledge more areas than administrative boundaries as their "neighborhoods." This problem exaggerates in cases where the administrative boundaries of neighborhoods cover huge or small areas of land. Davison & Lawson (2006) detected that children were less likely to actively commute to school if the school was more than 800 m away from the children's homes.

Based on the findings mentioned above, the author created 800 m radius circular buffers around each school and defined this area as children's neighborhood environment (herein, the term "neighborhood" defines this area) (see Figure 11). This process yielded nine neighborhoods that are located from the urban periphery. Five are located in Sincan district (SN1, SN2, SN3, SN4, SN5) and four are located in Çankaya district (CPN1, CPN2, CPN3, CPN4). Additionally, it yielded seven neighborhoods that are located in the inner-city. Four are located in the Çankaya district (CN1, CN2, CN3, CN4), and three are located in the Mamak district (MN1, MN2, MN3).

Neighborhoods that are located close to each other in the same district are defined as a region in this thesis. It is assumed that while neighborhoods that are located close to each other more or less demonstrate similar urban form characteristics, e.g., inner-city neighborhoods in the Çankaya district are assumed to represent similar urban form characteristics and that these characteristics are very different from the ones that are represented by the peripheral neighborhoods in Sincan district. This study clustered eight neighborhoods under four regions: Mamak Region, Çankaya Center Region, Çankaya Periphery Region, and Sincan Region. While Mamak and Çankaya Center Regions are considered inner-city regions, Sincan and Çankaya Periphery Regions are considered peripheral regions.

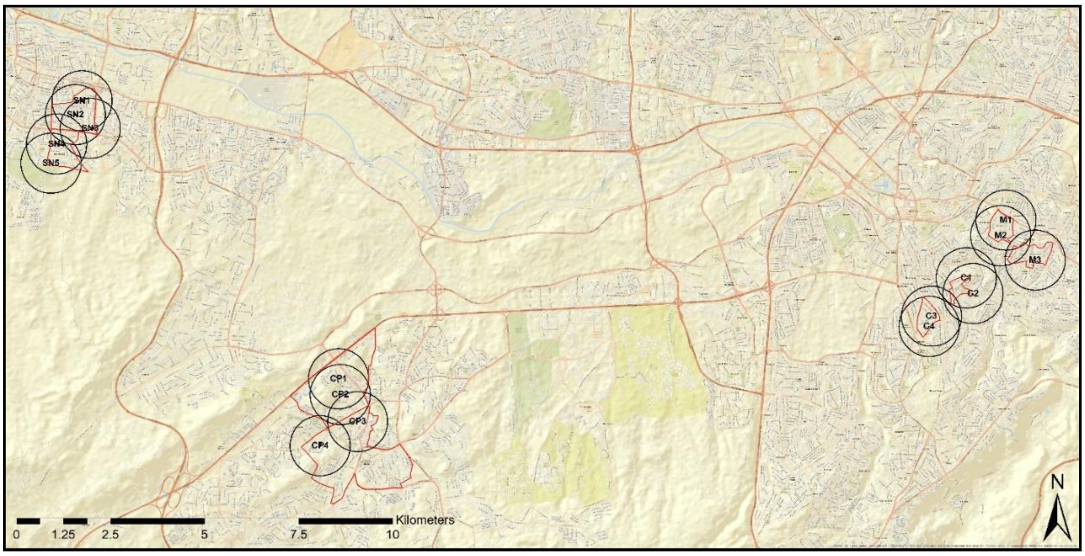


Figure 11. Administrative boundaries and created boundaries of selected neighborhoods

3.3 Data Collection

Three types of data were collected to answer the research questions of this thesis: data related to the urban environment, air quality, and childhood asthma (Figure 12). Except for the data related to childhood asthma and the natural environment, the author collected primary data.

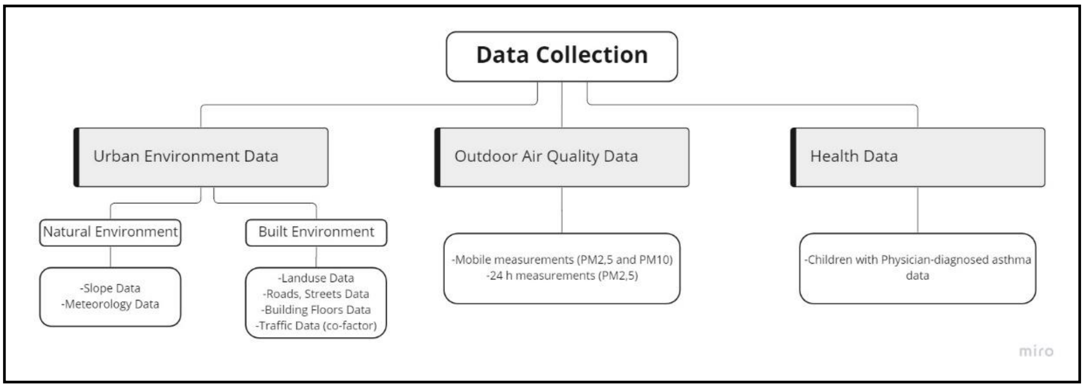


Figure 12. Data collected within the scope of thesis

3.3.1 Urban Environment Data

Urban environment, as is used in this thesis, refers to the natural and built environment. The natural environment data were obtained from several institutions. Built environment data, however, is collected by a number of researchers, including the author of this thesis.

Altitude and meteorology (temperature, wind speed and direction, and relative humidity) data are part of the natural environmental data. The altitude data of the neighborhoods were obtained from the Ankara Metropolitan Municipality in Netcad format. Meteorology data was obtained from the General Directorate of Meteorology. This data was obtained on an hourly and station basis for particular dates – the dates on which the author monitored the street-level air quality in the chosen neighborhoods. There were eight stations in or near the chosen neighborhoods (for the locations of these stations, please see Figure 13). This thesis used the data obtained from these eight sources.

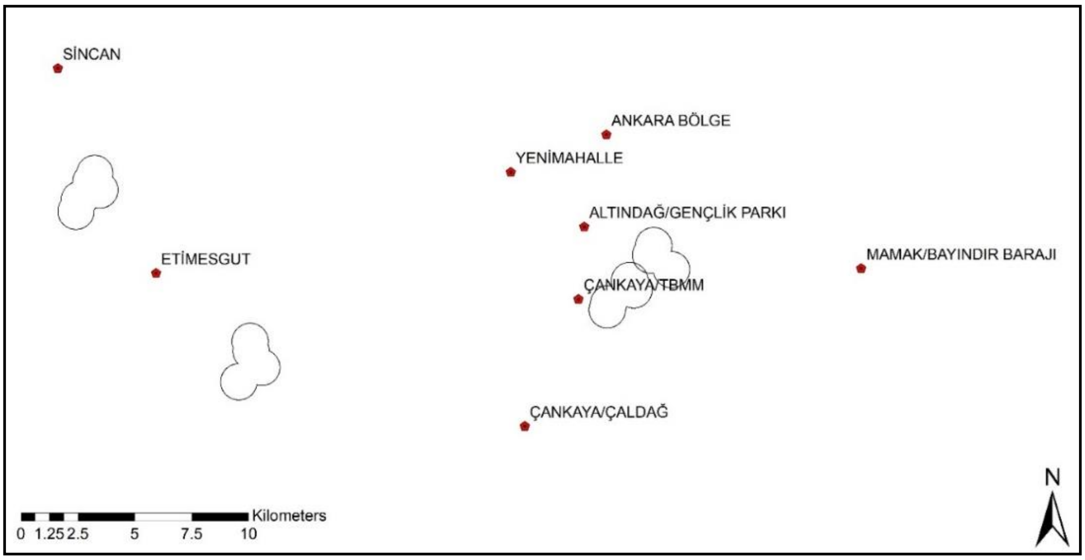


Figure 13. Locations of meteorology stations

The built environment data were taken from the Ankara Metropolitan Municipality in Netcad format. This data was created between 1995 and 1999. They were outdated and did not accurately depict the current situation of the selected neighborhoods.

Therefore, these data were updated by the author and a team of researchers within the scope of a TÜBİTAK-funded project (no. 219K243). During this process, together with some other researchers, the author visited each neighborhood to document the urban form characteristics (like land use and building height) of the chosen circular buffers. The research team also used satellite images to check the existing street networks and the layouts of the existing buildings. The following is a synopsis of the steps taken during this process. The process started with the preparation of the base maps. This process was followed by three stages, including the data cleaning and generation process.

The first stage covers the process of creating the draft map bases by using satellite images in the Netcad environment. Step-by-step work that was done at this stage is explained as follows:

1- The polygon drawings of each building, porch, and building block polygons were cross-checked: if the polygons were drawn more than once, only one was retained. Also, all non-closed polygons were closed.

2- If the buildings, porches, and building blocks did not match the satellite images, they were deleted. These layers were redrawn as polygons by referring to the satellite images.

3- The road medians, parks, and hard surfaces like parking lots and school gardens were drawn as a separate layer and polygon.

4- All points, lines, and polygons outside the boundaries of the neighborhoods were deleted.

The second stage was the collection of field data. This stage aimed to update the data obtained from Ankara Metropolitan Municipality in the context of analyzing the mesoscale urban form elements considered within the scope of the project and this thesis. At this stage, the chosen neighborhoods were physically visited. Information regarding the urban form characteristics of these areas was collected from the field. Streets were visited in the selected regions, and coding was made on the bases in the field by looking at the characteristics of each building/block. An example of a map created during fieldwork can be seen in Figure 14. Information from two different kinds of literature was effective when coding: (1) the presence of land uses that may affect outdoor air quality (such as industry and gas stations) (see McCarty & Kaza, 2015; Voros et al., 2019), and (2) the existence of land uses that attract or push children into open public spaces, thus affecting the degree of breathing of outdoor air (see, Sancar & Severcan, 2010; Severcan, 2018). The urban features coded in this context are:

1- Function of non-building blocks: park/recreation areas, open car parks, unused car parks, or vacant lands that can be used as playgrounds

2- Land use of the ground floors of the buildings: housing, traditional commercial uses, specialized commercial uses (shopping centers, super- and hyper-markets), education, public institutions/structures (such as town hall, headman's office, cultural center), gas station, industry, other (such as warehouses and workplaces)

3- Construction areas

4- Number of floors of the buildings

5- Roads

During the data collection phase, the buildings that were not seen in the field but seen in the satellite images were noted and then deleted from the drawings. Similarly, the cases where buildings were seen in the field but not seen in the satellite images were drawn to the bases as accurately as possible to analyze the most up-to-date situation of the urban form characteristics of the chosen neighborhoods.

Figure 14. Base maps created during the fieldwork

The third stage was the final pre-analysis process. Step-by-step work that was done at this stage is explained as follows:

1- In line with the information obtained from the field studies, the buildings that were not visible on the Netcad bases were drawn as polygons. The buildings that were not seen in the field studies but appeared on the Netcad bases were deleted from the digital bases in order to reflect the most up-to-date situation.

2- Park areas, hard surfaces (such as the hard surfaces in schoolyards), forested areas, undesignated areas, road medians, and parking lots were updated after the fieldwork.

3- For the calculation of street connectivity, the centers/midlines of the roads were drawn as “lines” (each line was drawn in separate segments from one road intersection to another so that the street connectivity analysis could work correctly in ArcGIS).

4- Once the bases were updated in the Netcad environment, they were transferred to the ArcGIS environment for analysis. In this transfer phase, the projection system, UTM 30, was converted to UTM 60 to obtain more valid results. This conversion was also made because UTM 3^0 was not among the defined projection systems in the ArcGIS database. This translation allowed it to overlap the satellite images opened in the ArcMap environment and the vector data. Also, the GCS_TUREF (more specifically, TUREF_TM 33) was used as Geographic Coordinate System.

5- In ArcGIS, data for the building floor areas (in m^2), the number of building floors, the land use for the whole building, and the land use of the ground floor were coded to the attribute table of each building. The building floor area was calculated using ArcGIS's Calculate Geometry tool.

6- Other polygon feature areas, such as park areas, forested areas, undesignated areas, etc., were also calculated using the Calculate Geometry tool in ArcGIS.

7- The industrial areas in Ankara that could affect the air quality in studied regions are drawn.

In addition to these urban environment characteristics, this thesis also uses traffic data. Data for the automobile traffic was created in ArcGIS by referring to the images received from Yandex Maps based on the forecasts for the specific days and times of the air quality measurements (Table 1). The data of the roads on the measurement dates could not be investigated since Yandex Maps, or any other database could not provide historical data. Yandex produces forecasts for the specified days and hours based on the previous traffic volume on the roads (Yandex, 2022). Using this feature of Yandex Maps, screenshots were taken from the website based on the measurement days and hours.

Traffic data was obtained from Yandex Maps at hourly intervals from the start time to the end time of the measurement for each day of mobile measurements. For example, images were downloaded from Yandex Maps for the traffic density on the roads in the Çankaya Center region at 09.15, 10.15, and 11.15 hours for the measurement taken in Çankaya Center region between 09.13 - 12:00 on 02.11.21 Tuesday and images of 14.30, 15.30, and 16.30 were taken for the measurements taken in Çankaya Center region between 14.29 – 17.26 on 04.11.21 Thursday (Figure15). This process was repeated for each measurement day.

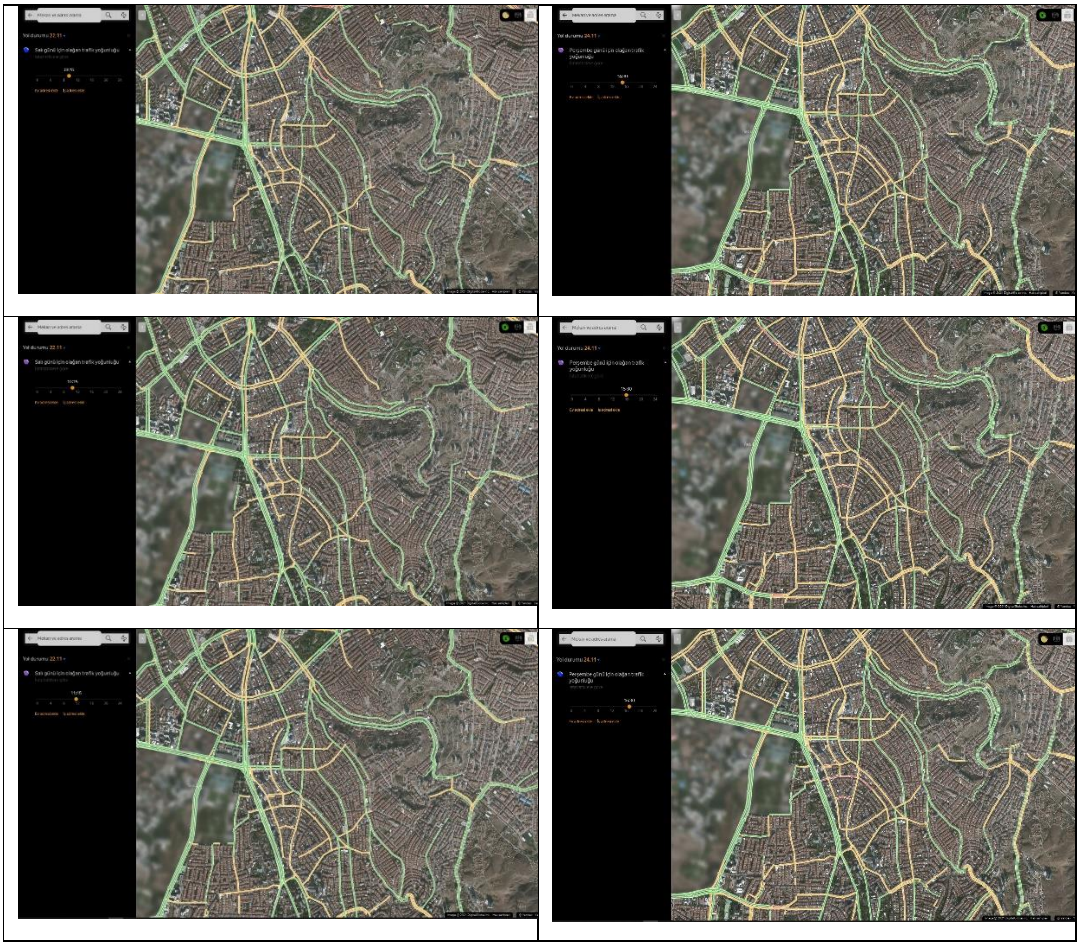


Figure 15. Traffic volume data of Çankaya Center Region for Tuesday and Thursday measurements

3.3.2 Outdoor Air Quality Data

The complex mixture of airborne pollutants that forms outdoor air pollution in urban environments can cause childhood asthma in a number of different ways. Outdoor air pollution’s components include particulate matter (PM) and gaseous pollutants such as ozone, nitrogen dioxide (NO2), volatile organic compounds, carbon monoxide (CO), and sulfur dioxide (SO2). PM varies in its composition and size, and is usually classified into 3 size groups: coarse particles (PM10, diameter <10 and ≥2.5 μm), fine particles (PM2.5, diameter <2.5 μm), and ultrafine particles (<0.1 μm) (Hadley et al., 2018a). Within the context of this thesis PM10 and PM2,5 concentrations are measured.

Outdoor air quality data used in the literature is mostly stationary data (Bayraktar & Turalioglu, 2005; Cao & Cai, 2022; S. Huang et al., 2020; Kurkcuoglu & Zengin, 2021). However, as Bayraktar & Turalioglu (2005) stated in their study, samples taken from a single point or a limited number of points throughout the city give information about average city concentrations; determination of local, neighborhood scale concentrations requires recourse to multi-point sampling studies. Within the scope of this thesis, PM10 and PM2.5 measurements were taken from multiple points in the selected regions.

Air quality measurements were made with two real-time air quality devices (Dust Trak II Aerosol Monitor 8530) in the chosen neighborhoods (Figure 16.1). The device (herein Dust Trak II) employs light scattering technology to deliver real-time measurements. The detection range is from 0.001 to 400 mg/m3 with a resolution greater than 0.001 mg/m3 or 1% of the reading. The particle size range is from 0.1 to 10 μm (TSI, 2022) Each particle is measured using a different cap (Figure 16.5). PM measuring caps are cleaned before each measurement and used by applying impact oil (Figure 16.10). There are zero filters on the device, every time the devices are turned on; they must be filtered (Figure 16.2). Although the devices have batteries (Figure 16.4), since the measurements took a long time, the devices were connected to the car with a converter throughout the mobile measurements (Figure 16.8.), and the devices were operated by connecting to the socket in both mobile and 24h measurements (Figure 16.3). With specific tools, the device can also take measurements outside for long time periods (Figure 16.7). Unfortunately, the author did not have such types of equipment.

Within the scope of this thesis, PM10 and PM2,5 pollutants were measured with Dust Track II. These particulate matter sizes are defined as air pollutants and have limit values defined by different establishments (e.g., WHO, TR Ministry of Environment, Urbanization, and Climate Change). The devices were burrowed from the Air Pollution Research Laboratory of Eskişehir Technical University Environmental Engineering Department. The author learned how to use the devices from the experts in this Laboratory. The data interval can be set in the devices as hourly, minute, or second. Within the scope of the thesis, minute-by-minute data were collected in each region. Devices have their own software named TaskPro (Figure 16.6) to transfer the data to the computer. The USB interface cable transfers device data to the computer (Figure 16.9). After opening the data in TaskPro software, the data was transferred to Microsoft Excel.

The points where the measurements were taken were marked on their geographical locations in the Google Earth program. Then the data was saved as KML. KML data is called to the ArcGIS software as point data. All air quality measurement data were organized in Excel and were thereafter transferred to attribute tables of the points in the ArcGIS environment.

Dust Track II device has been frequently used in previous research by other scholars in indoor environments (Kic, 2016), in studies that made comparisons between indoor and outdoor environments (Levy et al., 2002; F. Wang et al., 2016), and in outdoor environments (Kumar et al., 2018; Ormanova et al., 2020; Qu et al., 2019; Westerdahl et al., 2008). Some studies used this device to monitor outdoor air quality. Some took the measurements while walking (Chan et al., 2002; Dionisio et al., 2010; Zwack et al., 2011), some took the measurements while cycling (Qiu et al., 2019), some took the measurements while driving (Pirjola et al., 2012), and some took measurements using different styles of transportation; walking, cycling, driving (de Nazelle et al., 2012; Quiros et al., 2013).

Figure 16. Dust Track II Device and its equipment

The measurements were taken by two different methods within the scope of this thesis; First, by fixing the devices to an automobile while driving (Mobile Measurements), and second, by placing the devices at a selected school in the neighborhood for 24 hours (24 hours point-based measurements). The timetable for mobile and 24-hour measurements can be seen in the table below (Table 1).

Table 1. The timetable of mobile and 24h air quality measurements

		Tuesday 02.11.2021	Wednesday 3.11.2021	Thursday 4.11.2021	Friday 5.11.2021	Saturday 6.11.2021	Sunday 7.11.2021	Monday 08.11.2021	Tuesday 09.11.2021	Thursday 11.11.2021	Friday 12.11.2021	Saturday 13.11.2021	Sunday 14.11.2021	Monday 22.11.2021	Tuesday 23.11.2021	Wednesday 24.11.2021	Thursday 25.11.2021
Çankaya Center Region	CN1																
	CN2																
	CN3																
	CN4	09.13-12.00		14.29-17.26			11.13-13.50										
Çankaya Periphery Region	CPN1																
	CPN2																
	CPN3																
	CPN4		14.22-17.28		08.49-11.49	12.10-14.39											
Mamak Region	MN1																
	MN2																
	MN3							09.05-11.15			14.41-16.43	12.32-15.00					
Sincan Region	SN1																
	SN2																
	SN3																
	SN4																
	SN5								08.24-10.53	14.08-16.30			12.24-15.07	Sincan and 75.yıl primary schools 24 hours PM2.5 measurements	Sincan İMKB and Abidinpaşa primary schools 24 hours PM2.5 measurements	Avni Akyol and Teğmen kalmaz primary schools 24 hours PM2.5 measurements	Mimar Sinan and Münevver Öztürk secondary schools 24 hours PM2.5 measurements

3.3.2.1 Mobile Measurements

In mobile measurements, the devices are fixed on the hood of the car. First, a non-slip floor was placed on the car's hood. In order to place the devices on this floor, two baskets were fixed by using belts. After the devices were placed in the baskets, stabilizing rubbers were used to prevent the devices from falling or moving (Figure 17). Studies that took mobile measurements while driving either placed the devices inside the car and left the windows open (Quiros et al., 2013) or turned the car into a measuring device using the necessary equipment (Pirjola et al., 2012). Within the scope of this thesis, because there was no funding, the researcher turned her car into a measuring device. She also preferred not to place the Dust Track II device inside her car to better capture the outdoor air quality.

Figure 17. Created kit on the car's hood to take mobile measurements

The devices were located on the hood of the car at a height of 1.1 m from the ground, in line with the information that the average breathing height of children ranges from 0.7 to 1.5 m (Rivas et al., 2016). During the mobile measurements, the air conditioner of the car was turned off and the windows were open.

Mobile measurements took place within each region shaped by defined 800m radius neighborhoods, but the analysis has been made for each region which will be explained in detail under the section entitled “3.3.2 Air Quality Data Analysis”. Mobile measurements were taken on the streets. This is because children walk to school more often using street, and arguably, spend more time in the streets compared to other outdoor neighborhood places (Kurka et al., 2015; Ozbil et al., 2016). Before starting the mobile measurements, different street types have been determined to decide where the measurements should be taken while driving. Such a pre-determination was necessary to obtain more valid and generalizable results that accurately represent the outdoor air quality levels of the chosen neighborhoods in a short time period. The author assumed that similar types of streets would yield similar PM values; since there were too many street segments inside the buffers, the author wanted to filter some of them so that generalizable data could be received at the end of the PM measurement process. In the mobile measurements, the researcher stopped for about 3-6 minutes at each measurement point to capture the exact PM2.5 and PM10 values of the points located in different street typologies. Streets were classified as transit corridors, downtown thoroughfares, neighborhood main streets, neighborhood streets, unpaved streets, and internal roads of gated communities. Additionally, when measurement points were chosen, consideration was given to selected schools, open green spaces, and gas stations (Figure 18).

The concept of the transit corridor, as used in this thesis, includes the roads that serve the whole city, where the bus lines pass transit or with limited stops. Atatürk Road in the Sincan region, Mamak Road in the Mamak region, Atatürk Boulevard in the Çankaya Central region, and Dumlupınar Boulevard in the Çankaya Peripheral region are considered transit corridors.

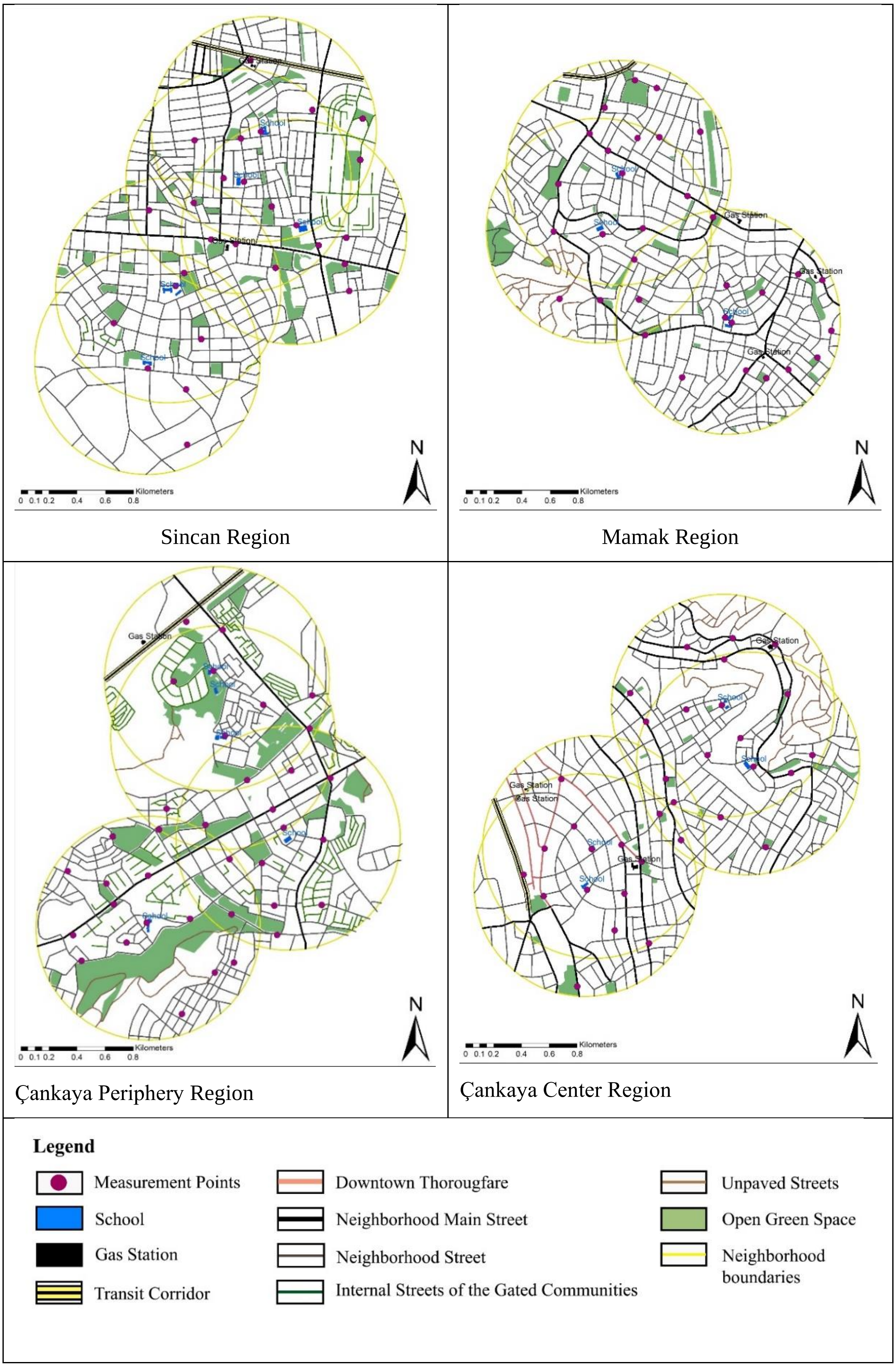


Figure 18. The criteria used to define measurement points

Downtown thoroughfare refers to major streets serving the entire city of Ankara and not just the neighborhoods they are in. These streets have significant traffic volumes at peak hours and bustle with activity throughout the day (NACTO, 2013). Within the scope of this thesis, four streets are considered as a downtown thoroughfare from Çankaya Center Region, which are Tunalı Hilmi, Tunus, Bestekar, and Esat roads. There is no other streets showing the characteristics of downtown thoroughfare in studied regions.

The neighborhood main street concept refers to the major streets that serve the neighborhoods; respectively have commercial areas alongside and have more car and pedestrian traffic than neighborhood streets.

Neighborhood street refers to local streets in residential areas that have local stores and schools. Internal streets of gated communities refer to streets that only serve the gated sites, and unpaved streets refer to the streets with no cover. Unpaved streets are seen in slum areas in Mamak and Çankaya Center regions.

When we analyze the overall situation in regions, in Sincan Region, there is a transit corridor within the SN1 neighborhood border. There are two gas stations, and we can see gated communities in the region. There are four types of streets in the Sincan region: transit corridors, neighborhood main streets, neighborhood streets, and internal streets of gated communities. In line with this information, 27 measurement points were chosen from the region.

In Mamak Region, there is one transit corridor within the MN1 neighborhood border. There are three gas stations, and three of them are within the MN3 neighborhood border. There are four types of streets: transit corridors, neighborhood main streets, neighborhood streets, and unpaved streets. In line with this information, 32 measurement points were chosen from the region.

In Çankaya Periphery Region, there is one transit corridor and one gas station inside the CPN1 neighborhood border. There are gated communities in the region. There are five types of streets: transit corridors, neighborhood main streets, neighborhood streets, internal streets of gated communities, and unpaved streets. In line with this information, 36 measurement points were chosen from Çankaya Periphery Region.

In Çankaya Center Region, there is one transit corridor that is inside the border of CN3 and CN4 neighborhoods. There are four gas stations and four different types of streets. Street types in the region are transit corridors, downtown thoroughfare, neighborhood main streets, neighborhood streets, and unpaved streets. In line with this information, 33 measurement points were chosen from Çankaya Center Region.

The purpose of taking mobile measurements is to determine how the air quality changes at street level and to be able to make a connection with changing environmental characteristics. Instead of taking measurements at limited numbers of points located at certain distances to represent the studied neighborhoods, gas stations that are known to have an impact on air pollution, schools that are known to be places where children spend their most time, open and green spaces where children are likely to spend time, and different street types are taken into account. All in all, 128 measurement points have been determined within the scope of this thesis (33 from the Çankaya center region, 36 from the Çankaya periphery region, 32 from the Mamak region, and 27 from the Sincan region).

Before starting mobile measurements, the principals of each school were informed about the process. The entrance and exit times of the schools were learned from the principals. Mobile measurements were repeated twice in each region on weekdays, one in the morning (tried to coincide with the schools' entrance time) and one in the afternoon (tried to coincide with schools' exit time). One measuring day was conducted over the weekend in each study region. In these measurements, the researcher tried to coincide with the noon hours when children could go out and play. The measurement schedule can be seen in Table 2. While the mobile air quality measurements were taken, the researcher stopped the car for 3 to 6 minutes at the designated points to measure PM2.5 and PM10 simultaneously. The stop time was noted along with the number of the stops (like point 1, 08:26 am) on a base map during these pauses.

Table 2. The date and times of measurements in each region

		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
		01.11.2021	02.11.2021	3.11.2021	4.11.2021	5.11.2021	6.11.2021	7.11.2021	08.11.2021	09.11.2021	10.11.2021	11.11.2021	12.11.2021	13.11.2021	14.11.2021
Çankaya Center Region	CN1														
	CN2														
	CN3														
	CN4		09.13-12.00		14.29-17.26			11.13-13.50							
Çankaya Periphery Region	CPN1														
	CPN2														
	CPN3														
	CPN4			14.22-17.28		08.49-11.49	12.10-14.39								
Mamak Region	MN1														
	MN2														
	MN3								09.05-11.15				14.41-16.43	12.32-15.00	
Sincan Region	SN1														
	SN2														
	SN3														
	SN4														
	SN5	Rainy								08.24-10.53	Off day	14.08-16.30			12.24-15.07

We coincide the measurement times with school entrance and exit times because most children are on the streets, and traffic is high around the schools during these hours. Also, the reason for taking measurements in each study area on a weekend other than school days is to be able to represent the areas on weekly basis. Some pictures from field study can be seen in Figure 19.

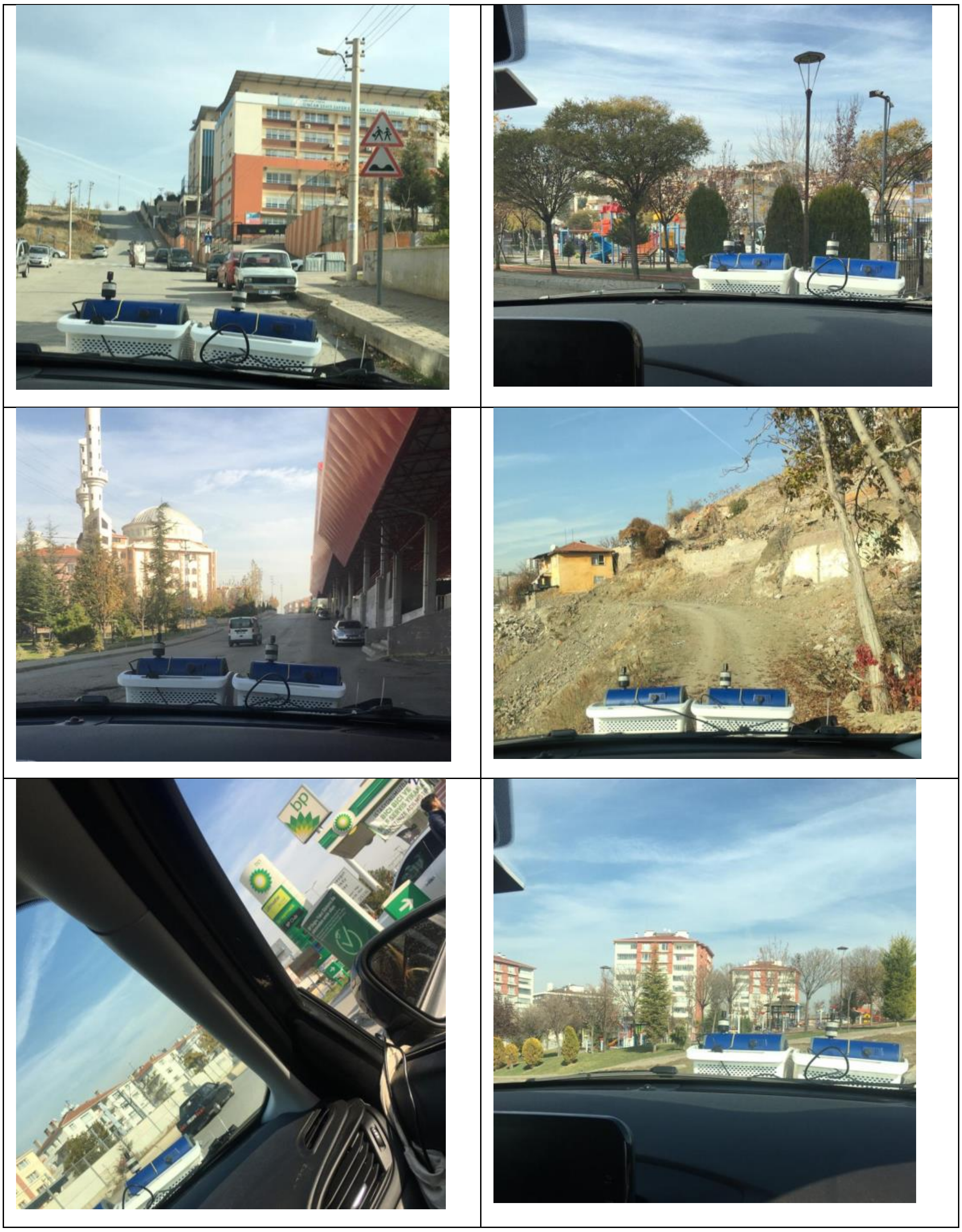
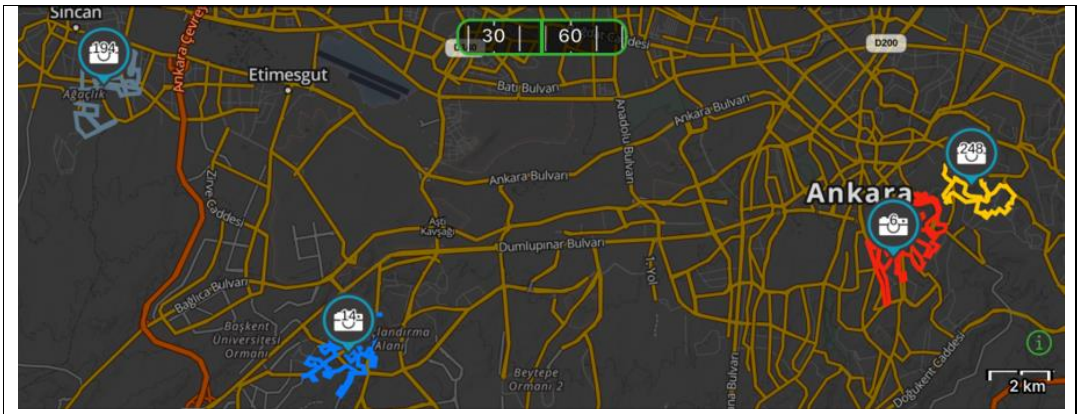


Figure 19. Pictures from mobile air quality measurements

Gaia Gps software was used to record the tracks of the taken routes and to make sure that the author stopped at the right places that were pre-selected before the journal for the air quality measurements. Gaia Gps is a gps that can be used offline, leave a trail on the map, and also mark points of interest with GPS coordinates and drop photo waypoints. Figure 20 illustrates the routes taken for the mobile measurements.

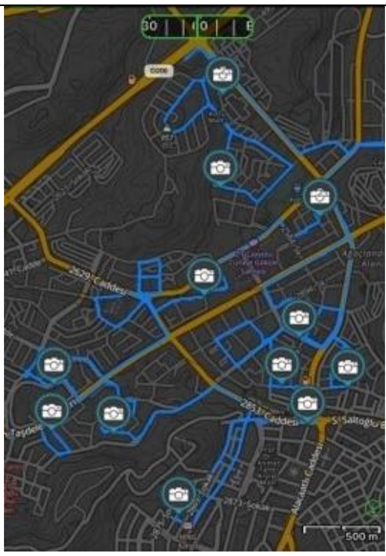
After the field measurements, when the air quality measurement data is transferred from the devices to the computer and refined, the first 2 min of data from the devices were deleted to guarantee the accuracy and stability of the samples at each measurement. By considering the minute information at the air quality measurement points, the arithmetic average value for each point was calculated and transferred to the ArcGIS.



Studied Regions

Sincan Region

Mamak Region



Çankaya Periphery Region

Çankaya Center Region

Figure 20. Gaia Gps traces of each studied regions

3.3.2.2 24 Hours Point-based Measurements

24-hour measurements were taken from eight schools located inside the chosen neighborhoods: one school from each neighborhood. Measurements were namely taken from CN1, CN4, CPN2, CPN4, MN1, MN3, SN2, and SN4 neighborhoods. The measurement points and the dates of the measurements can be seen in Figure 21.

Figure 21. Dates and the places of 24h measurements

Since the author had only two Dust Track II devices, it was not possible for the author to measure the PM values of the 8 points on the same period of time. To increase the validity of the findings, one of the devices was placed in one of the schools in the central neighborhood and the other one was placed in one of the schools in the peripheral neighborhood. Again, since the author had only two devices, in 24-hour measurements, only PM2.5 measurements were taken. In every school, the equipment is set up on a windowsill with a view of the school garden in an empty classroom or other interior space (Figure 22).

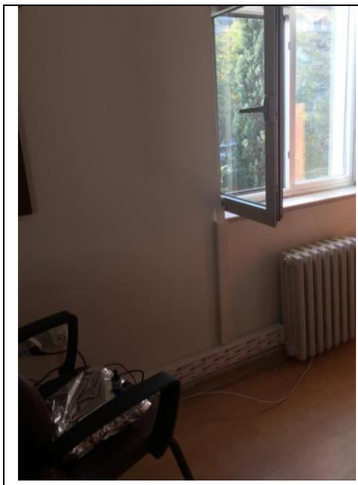
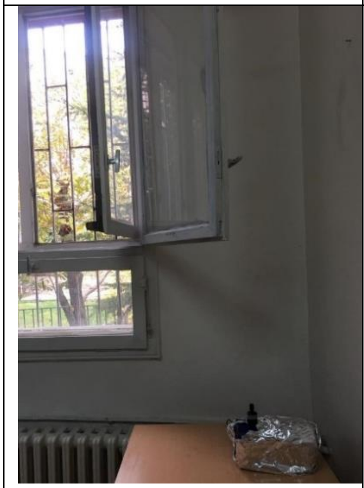
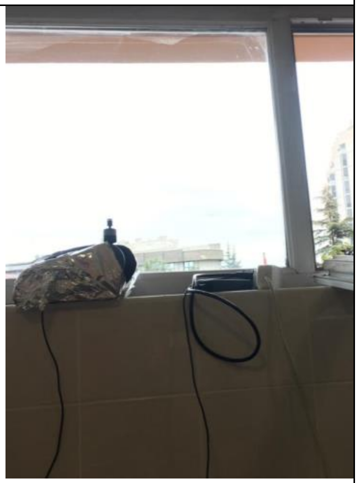
		
Sincan Primary S. (SN2) (3rd floor)	75.yıl Primary S. (MN3) (2nd floor)	Sincan İMKB P. S. (SN4) (4th floor)
		
Abidinpaşa P. School (MN1) (1st floor)	Avni Akyol P. S. (CPN4) (4th floor)	Teğmen Kalmaz P. S.(CN4) (2nd floor)
		
Mimar Sinan P. S. (CN1) (3rd floor)	Münevver Ö. P.S.(CPN2) (7th floor)	

Figure 22. Places where 24-hour measurements were taken

The reseacrher took measurements by leaving the window open for a full day. Only at Münevver Öztürk Secondary School in Koru neighborhood, measurements were made from the balcony of an apartment directly across from the school since the school couldn’t provide a closed space where the equipment could be kept secure in the school. The photographs of the places where measurements were taken and the information on which floor the measurement was taken can be seen in Figure 22.

The first measurement was made on Monday, 22.11.2021. One of the devices was placed in Sincan Primary School (SN2), and one in 75. Yıl Primary School (MN3). After the 24-hour measurements in these neighborhoods were completed, the devices were taken and placed in Sincan İMKB (SN4) and Abidinpaşa (MN1) Primary Schools (on Tuesday, 23.11.2021). On Wednesday, 24.11.2021, the devices were placed in Avni Akyol (CPN4) and Teğmen Kalmaz (CN4) primary schools. Thereafter, on Thursday, 25.11.2021, the devices were placed in Mimar Sinan Secondary School (CN1) and on an apartment balcony opposite Münevver Öztürk Secondary School (CPN2). The purpose of taking these measurements is to simultaneously compare one central and one peripheral neighborhood and to determine how the air quality changes during the day in schools, which are the areas where children spend the most time.

3.3.3 Health Data

The researcher obtained the children's asthma data from the Ministry of Health. This data was requested from the Ministry based on the ICD 10 diagnostic codes. J45 is the main code that shows the asthma status of children. Accordingly, the number of children diagnosed with asthma with the diagnosis codes J45, J45.0, J45.1, J45.8, and J45.9 was obtained along with the number of children registered to the family public health centers in the studied regions (WHO, 2022) (Table 3). The data used in this thesis includes information collected by health professionals until April 2021.

Table 3. ICD-10 diagnostic codes of asthma

J45	**Asthma**
J45.0	**Predominantly allergic asthma** Allergic: - bronchitis NOS - rhinitis with asthma Atopic asthma Extrinsic allergic asthma Hay fever with asthma
J45.1	**Nonallergic asthma** Idiosyncratic asthma Intrinsic nonallergic asthma
J45.8	**Mixed asthma** Combination of conditions listed J45.0 and J45.1
J45.9	**Asthma, unspecified** Asthmatic bronchitis NOS Late-onset asthma

The received data contains physician-diagnosed asthmatic patients and total registered children aged 0-6 and 7-12 years to the Family Public Health Centers (FPHC) located in or near the study areas (Figure 23). The reason for collecting the data from the FPHCs is as follows: according to the 8th article of the Ministry of Health Family Medicine Practice Regulation, "The directorate registers people for family physicians for the first time with considering their place of residence. Newborns, babies, and children who are not yet registered in the population are registered with the family physician whose mothers are registered" (Family Medicine Practice Regulation, 2013). This means that people living in a neighborhood are automatically registered at the nearest FPHC. Since asthma is a disease for which a report is written so that the drugs can be continued on an annual basis, all children who report their report and take medication from the FPHC are added to the database. Based on these information, the children with asthma in the research area were determined by averaging the number of children registered in the FPHC in and surrounding the identified neighborhood units. The same regulation also says, “People can freely choose their family doctor without any regional restrictions.” However, as mentioned in the first section of this chapter, during the COVID-19-related lockdowns in Turkey, the author could obtain information regarding the asthma status of children only for the chosen buffer areas. For this reason, the data obtained from the Ministry was accepted by the author. A total of 20 FPHC data was obtained – 5 of them were in the Çankaya Center Region, 5 in the Mamak Region, 7 in the Sincan Region, and 3 in the Çankaya Periphery Region.

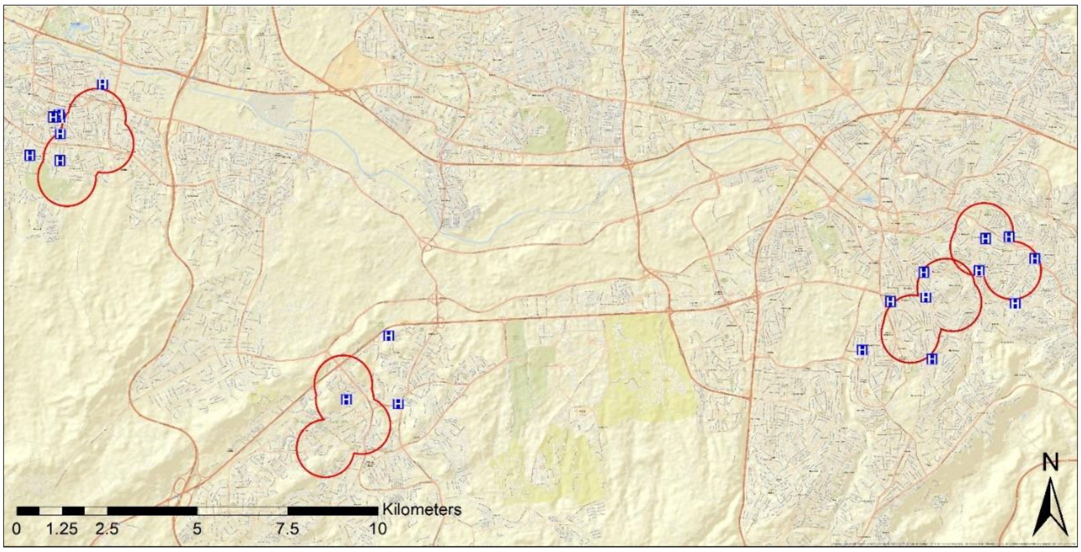


Figure 23. Family Public Health Centers’ exact locations

3.4 Data Analysis

Different analysis techniques were utilized for each built and natural environment variable. All urban environment, air quality, and health data were initially examined within their respective categories. Then, these data were analyzed using a variety of statistical techniques in order to answer the research questions posed in this thesis, all of which required the author to triangulate data obtained for the urban environment, outdoor air quality, and childhood asthma. In this section, how each data set is analyzed within its own category is explained in detail (please see Table 4 for a brief summary of the methods used in this phase of the data analysis).

Table 4. Urban Environment data analysis methods

	Description	Analysis Method	Examples from literature
Slope	The Z values of the geographical location of the studied regions	Interpolation, Ordinary Kriging	Sadeghi et al., 2017
Temperature	Stationary temperature values of Ankara	Interpolation, Ordinary Kriging	Shtiliyanova et al., 2017
Relative Humidity	Stationary relative humidity values of Ankara	Interpolation, Ordinary Kriging	Wang et al., 2020
Wind Speed	Stationary wind speed values of Ankara	Interpolation, Ordinary Kriging	Ibrahim et al., 2014
Figure-Ground	The solid/void ratio of the studied regions	Solid areas/Void areas in the region	Sarı and Aybek, 2018
Building Density	The surface area of the buildings multiplied by the number of floors divided by the studied regions	Formula below [a]	Tesfazghi et al., 2010
Land-use mix	Diversity of different land uses within the studied regions	Formula below [b]	Frank et al., 2005 He et al., 2020
Active Open and7 Green Areas	The ratio of soft surface areas except undesignated areas to studied regions	(Sum of soft surface areas- undesignated areas) / area of studied regions	-
Active+Passive Open and Green Areas	The ratio of soft surface areas to studied regions	Sum of soft surface areas / area of studied regions	-
Park Areas	The ratio of park areas to studied regions	Sum of park areas / area of studied regions	-
Proximity to industrial areas	Distance in kilometers between the studied regions and the two nearest industries	distance between the midpoints of regions and industrial areas	-
Street Connectivity	The ratio of the number of intersections in streets to the studied region	number of intersections / area of studied regions	Frank et al., 2005 Marshall et al., 2009
Traffic	The ratio of the length of roads that have traffic for each category to the studied region	The road length that has low, medium, or high traffic flow / area of studied regions	-
Air Quality (Mobile)	Measurement values of each point	Interpolation, Ordinary Kriging	Beauchamp et al., 2017
Air Quality(24h)	Measurement values of each point	Comparison of air quality between different neighborhoods	-
Childhood Asthma	The ratio of the number of Physician diagnosed children to all the children that are registered to FPHCs	Number of physician-diagnosed children / All children	Spira-Cohen et al., 2010

[a] Building Density = [(Floor area of building1) x (Numbers of floors at building1)] + (…) + [(Floor area of buildingn) x (Numbers of floors at buildingn)] / studied regions defined by 800m radius neighborhoods

[b] Land-use Mix = $\frac{(-1) \times [(b1/a) \times \ln (b1/a) + (b2/a) \times \ln (b2/a) + (b3/a) \times \ln (b3/a) + (\ldots) + (b8/a) \times \ln (b8/a)}{\ln 8}$

a= total square meter of land for all eight land uses present in the studied regions
b= square meter of building floor area in each land use

3.4.1 Analysis of the Characteristics of the Urban Environment

3.4.1.1 Slope Analysis

The “z” (altitude) values of contour lines were obtained from the Ankara Metropolitan Municipality as point data. This data was then exported to Netcad and ArcGIS. At first, by using the Netsurf > Create triangle > Curve it commands, the points were transformed into slope lines in Netcad. Next, point and line data with Z values were transferred to ArcGIS and projected to the TUREF33 Turkish projection system, which refers explicitly to Ankara city. In ArcGIS software, the interpolation method is used to create area-based slope base maps and statistical data.

Interpolation is a method used to predict values in the absence of documented observations for a location. It can alternatively be described as a process that uses current point measurements to estimate the values of properties at unsampled sites within the area covered (Algarni & el Hassan, 2001). Creating a digital model of the landscapes to represent the whole area is essential (Caruso & Quarta, 1998). Within the scope of this thesis, point data were transformed into area data using the interpolation method. Various interpolation models exist within ArcGIS software, including deterministic and geostatistical models. The most popular deterministic model is inverse distance weighting (IDW), while the Kriging model is the most popular geostatistical model. Although methods like IDW are used for spatially located data, Kriging methods are among the best known in the earth sciences (Myers, 1994).

Kriging overcomes many of the shortcomings of the traditional deterministic methods of interpolation incorporated in GIS. Kriging is the method of interpolation originating from regionalized variable theory. It relies on representing the spatial variation of the property in terms of the variogram, and it minimizes the prediction errors, which are themselves estimated (Desmet, 1997; Oliver & Webster, 2007). The Kriging estimate is known as the Best Linear Unbiased Estimate because it is a linear combination of the weighted sample values, whose expected value for error equals zero and whose variance is a minimum (Caruso & Quarta, 1998; Oliver & Webster, 2007). According to (Li & Heap, 2011), ordinary Kriging (OK), and ordinary co-kriging (OCK) are the most frequently used methods. In Zimmerman (1999) 's study that compares IDW, Universal Kriging (UK), and OK, it was found that the two Kriging approaches were significantly better than the IDW method across all levels of surface type, sampling pattern, noise, and correlation. Furthermore, OK outperformed UK slightly (Zimmerman et al., 1999).

Three forms of Kriging are commonly used, which are simple, ordinary, and universal Kriging. Simple Kriging assumes that the mean value is known, while with ordinary Kriging the mean value is assumed constant and determined during the interpolation. Universal Kriging assumes that the data follow a known trend (Son et al., 2010). In light of this information, the Ordinary Kriging method, the most commonly used Kriging method, is used in slope analysis.

Kriging interpolates the unknown data points with observed values through semivariograms (Burrough & Mcdonnell, 1998; Kurkcuoglu & Zengin, 2021; Tang, 2002). There are different types of semivariograms that can be used in the Ordinary Kriging method, such as spherical, circular, exponential, gaussian and linear (Figure 24).

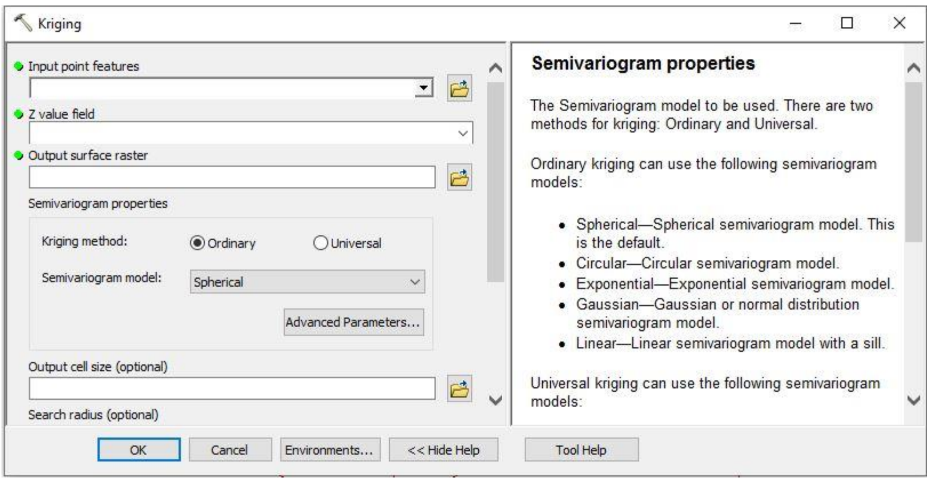


Figure 24. Semivariogram types in ArcGIS software

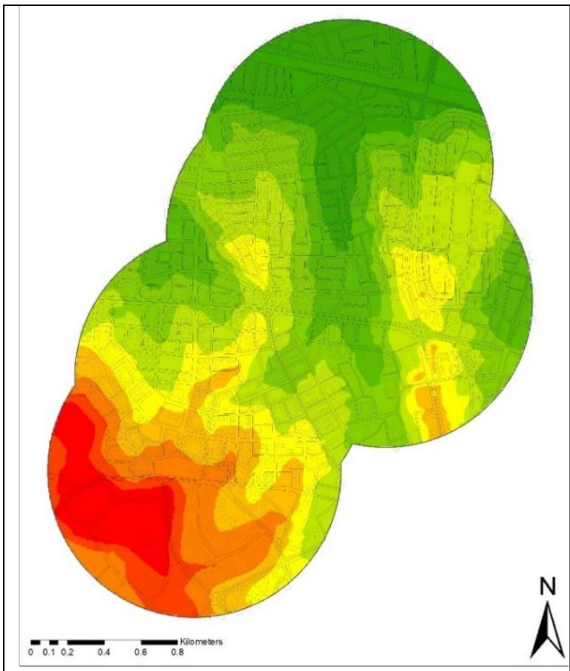
To define the best-fitting semivariogram type, prediction error values of the model output are used. The mean (ME) and the standardized mean (SME) values are expected to be close to 0, the root–mean–squared (RMSE) and average standard error (ASE) values are expected to be as small as possible, and the root–mean–square–standardized (RMStdE) value is expected to be close to 1(Esri, 2022; Hofierka et al., 2007; Kurkcuoglu & Zengin, 2021).

All of the point data obtained from the Ankara Metropolitan Municipality were examined. It was found that the error rates for all forms of semivariograms were low and very near to one another since there were too many points to adequately depict the neighborhood units being studied. The exponential method was chosen because it produces slightly more accurate findings than others (see Appendix C, Table C.1).

First, in order to increase the credibility of the altitude data, the researcher created 1600 m buffers around each school and included all the data inside 1600 m buffers. To run the analysis, Geostatistical Analyst > Geostatistical Wizard > Kriging-CoKriging > Type=Ordinary > Type=Exponential steps are followed. As mentioned before, in terms of performing interpolation as correctly as possible, the analysis was made within a 1600 m radius of schools (Figure 25). Later, the outcomes of this analysis were limited with the boundaries of the chosen neighborhoods (800 m radius buffers from the public schools).

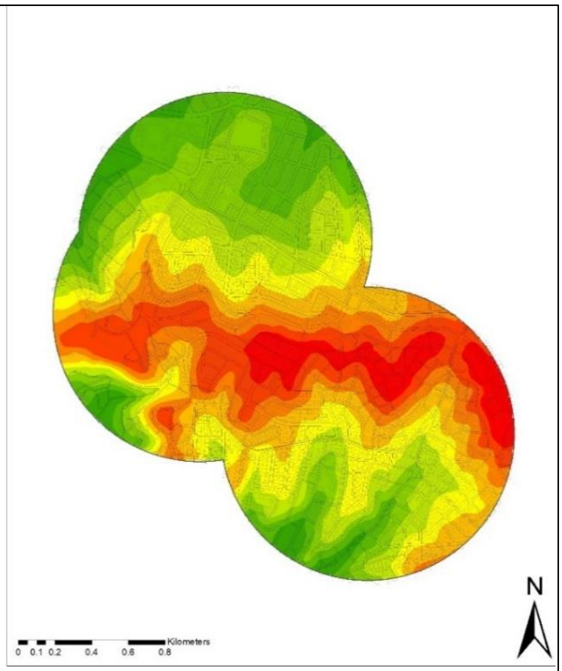
The slope analysis aims to determine to what extent the altitude, one of the characteristics of the natural environment of the study regions, affects the air quality. Although contradictory results exist (Dimitriou & Kassomenos, 2018), places at higher altitudes are expected to have more airflow, resulting in less PM10 and PM2,5 concentrations (Ning et al., 2018).

When we compare the regions in terms of their altitude, we can see that the standard deviation is lowest in the Sincan region, which means altitude does not differ as much as in other regions. The highest standard deviation is at the Çankaya center region. We can see that the areas with the highest altitude (1020,68) are in the Mamak region, while the areas with the lowest altitude (789,07) are in the Sincan region.



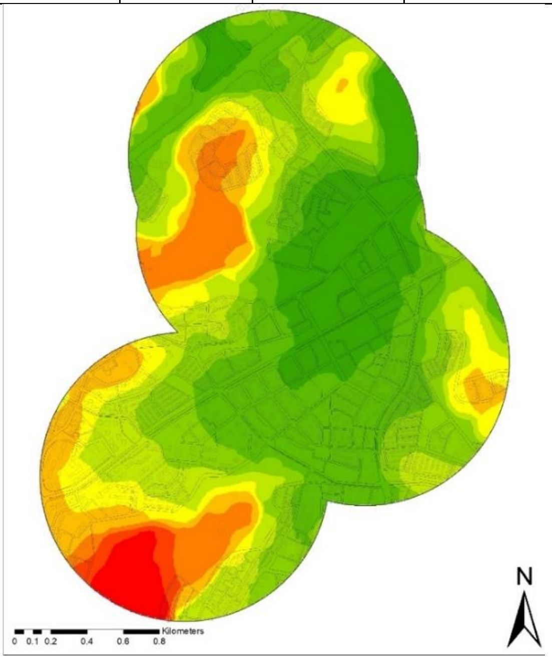
Sincan Region

Min 789,07	Max 888,86	Mean 824,98	SD 23,65



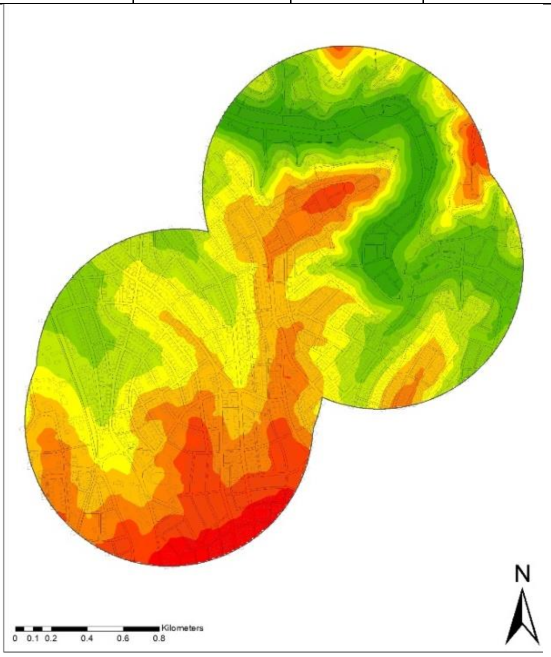
Mamak Region

Min 883,21	Max 1020,68	Mean 952,81	SD 25,25



Çankaya Periphery Region

Min 863,04	Max 998,86	Mean 904,17	SD 26,7



Çankaya Center Region

Min 862,38	Max 998,42	Mean 924,91	SD 27,54

Legend

Figure 25. Slope analysis of studied regions

3.4.1.2 Meteorological Analysis

As the previous chapter illustrates, meteorological data like temperature, relative humidity, and wind speed have an effect on urban air quality (Elminir, 2005; S. Kim et al., 2015). Meteorological data were analyzed separately regarding temperature, relative humidity, and wind speed. The hour-based data obtained from the General Directorate of Meteorology were refined according to the days and hours of air quality measurements. No temperature data was available for the Yenimahalle measurement station, and there was no wind speed data dated 08.11.2021 for the Çankaya/TBMM measurement station.

While refining the data, firstly, the researcher separated the temperature, relative humidity, and wind speed data of the hours in which the air quality measurements were taken. Then, data sets were created using the arithmetic average of measurement hours among themselves. In 24-hour measurements, the data were created by taking the average of 24 hours of the days the measurements were taken. Afterward, the refined data was transferred to the attribute table of the station points in ArcGIS. There was also hour-based wind direction data (in degrees unit) in the data obtained from the General Directorate of Meteorology. However, this data was not used because the arithmetic average of the hourly data cannot be taken in this data.

There is no meteorology station among the chosen neighborhoods. That's why, while analyzing the area, estimations had to be done. Estimates about the study area were made using ArcGIS's interpolation tool. The most commonly used interpolation method, Ordinary Kriging, was also utilized in meteorological analyses, as mentioned in the "slope analysis" section. The Ordinary Kriging method is often used in research to estimate temperature (Holdaway, 1996; Rü, 2015; Shtiliyanova et al., 2017), relative humidity (Nguyen et al., 2015; Villagran & Bojacá, 2020; T. Wang et al., 2020), and wind speed (Ibrahim et al., 2014; B. Liu et al., 2013). For choosing the best-fitting semivariogram type, prediction error values of the model output were used (see Appendix C, Table C.2). The linear method was selected in light of the error values.

One example of the humidity data map for 25.11.2021 is shown in Figure 26. This process is repeated for each measurement day and data set. OK interpolation process was performed for each day of measurement for temperature, relative humidity, and wind speed data separately. Then, raster data were clipped by using the boundaries of studied regions. In the last stage, Table 5 was created for temperature, relative humidity, and wind speed by taking the mean values of the region's boundary data.

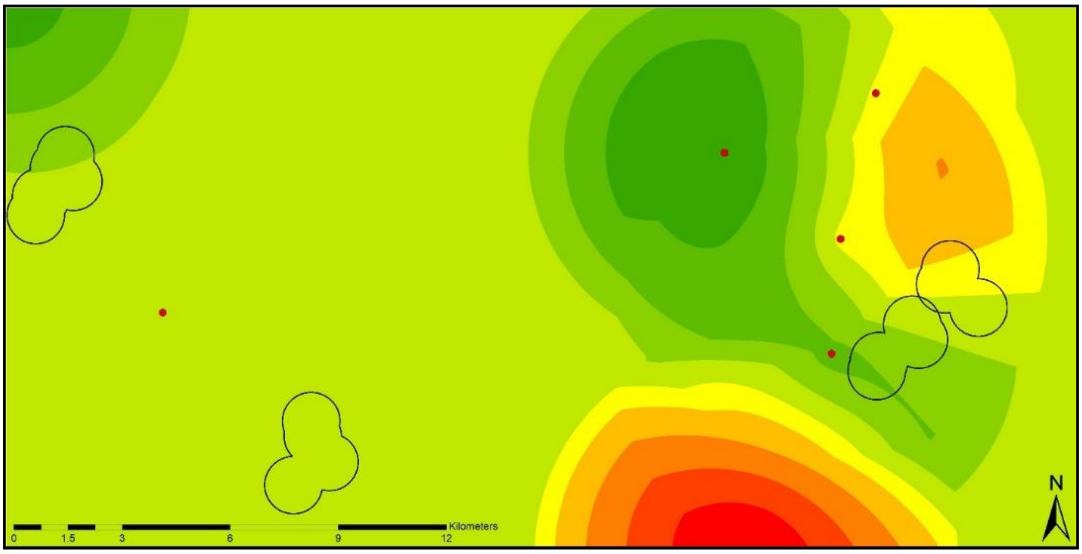


Figure 26. Humidity data map for 25.11.2021

When we examine the meteorological data, it is observed that there is a break in temperature after the 11th of November; the temperature decreases after this particular date. An examination of the data regarding the relative humidity demonstrates that relative humidity varies according to the dates. When the regions are examined in terms of wind speed, it is seen that the wind speed was highest in the Çankaya central region on 02.11.21 and in the Sincan region on 11.11.21 and 23.11.21.

Table 5. Meteorological values for measurement days and times

		2.11.2021	3.11.2021	4.11.2021	5.11.2021	6.11.2021	7.11.2021	8.11.2021	9.11.2021	11.11.2021	12.11.2021	13.11.2021	14.11.2021	22.11.2021	23.11.2021	24.11.2021	25.11.2021
Temperature (°C)	Sincan Region								17,8	6,6			12,5	7,3	9,7		
	Mamak Region							19			7,1	11,8		7,2	9,7		
	Çankaya Periphery R.		14,7		16,1	19										5,8	6,4
	Çankaya Center Region	16,6		15,1			20,7									5,6	5,9
Relative Humidity (%)		2.11.2021	3.11.2021	4.11.2021	5.11.2021	6.11.2021	7.11.2021	8.11.2021	9.11.2021	11.11.2021	12.11.2021	13.11.2021	14.11.2021	22.11.2021	23.11.2021	24.11.2021	25.11.2021
	Sincan Region								47,2	44,7			39,6	62,7	73,3		
	Mamak Region							42,2			51,9	39,3		70,6	78,5		
	Çankaya Periphery R.		75,8		57,6	40,6										81,7	77,1
	Çankaya Center Region	64		66,5			35,2									82,9	74,9
Wind Speed (m/sn)		2.11.2021	3.11.2021	4.11.2021	5.11.2021	6.11.2021	7.11.2021	8.11.2021	9.11.2021	11.11.2021	12.11.2021	13.11.2021	14.11.2021	22.11.2021	23.11.2021	24.11.2021	25.11.2021
	Sincan Region								1,5	2,6			1,6	1,5	3,2		
	Mamak Region							1,3			0,9	0,7		1,2	1,5		
	Çankaya Periphery R.		1,4		1,5	1,8										3	2,3
	Çankaya Center Region	3,2		0,5			0,9									1,4	0,8

3.4.1.3 Figure – Ground Analysis

The figure-ground analysis was used to evaluate whether changes in the quantity and ratio of solid and void areas in the analyzed regions are related to air pollution. For the analysis, the ArcGIS database obtained from the Ankara Metropolitan Municipality (later updated within the scope of the aforementioned TÜBİTAK project) was used. The floor areas of the buildings and porches referred to solid areas; other empty spaces are considered void areas. Figure-Ground analysis was obtained by dividing the total solid areas by the total void areas in each studied region.

In Figure 27, we can see the results of the figure-ground analysis. It is seen that percentage of void space is more in each region. According to the analysis results, the region with the least solid density is the Çankaya periphery region (*0.12*), and the region with the highest solid/void ratio is the Mamak region (*0.43*). When the peripheral and central regions are compared, in general, it is seen that the central regions are denser than the peripheral regions in terms of solid/void ratio.

Sincan Region			Mamak Region		
Solid: %19,34	Void: %80,66	Solid/Void: 0.24	Solid: %30,12	Void: %60,98	Solid/Void: 0.43

Çankaya Periphery Region			Çankaya Center Region		
Solid: %10,49	Void: %89,51	Solid/Void: 0.12	Solid: %28,53	Void: %71,47	Solid/Void: 0.4

Figure 27. Figure-Ground analysis of the regions

3.4.1.4 Building Density Analysis

The following formula was used while calculating the building density (for studies that used the same formula, see, e.g., Tesfazghi et al., 2010):

Building Density = [(Floor area of building 1) x (Numbers of floors at building 1)] + (…) + [(Floor area of building n) x (Numbers of floors at building n)] / Area of studied regions defined by 800m radius neighborhoods

Looking at the results of this analysis (Figure 28), it is seen that the region with the highest building density is Mamak (*1.24*). In the Çankaya Center Region (*1.13*), embassies occupy large amounts of area in the southwest and the unplanned slum area in the northeastern part of the region. Thus, the building density of this region is lower than the building density of Mamak. Results also show that the region with the lowest building density is the Çankaya periphery (*0.47*), and this region is followed by Sincan (*0.97*).

When the periphery and center regions are compared to one another, as in the Figure-Ground analysis, it is seen that the building density in the periphery regions is lower than in the central regions.

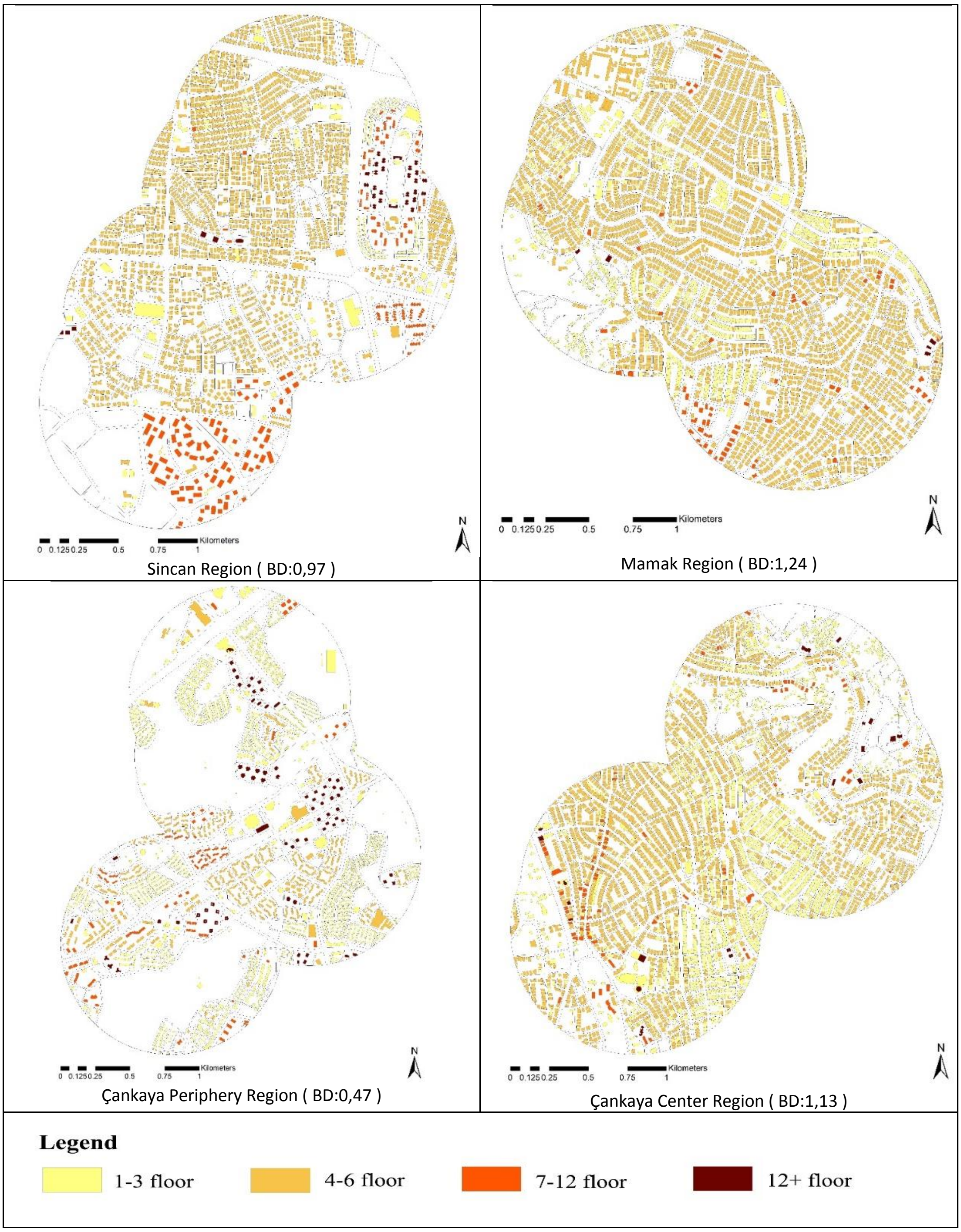


Figure 28. Building Density Analysis of the regions

3.4.1.5 Land-use Mix Analysis

Land-use mix analysis was conducted to investigate the land use diversity in each study area and whether it affects air quality. The legend of Figure 29 was determined for the land uses in the studied regions during the fieldwork. In this study, the term land use mix refers to building land use mix (note that there are also studies that conduct land use mix for building parcels). We considered the buildings' uses as a whole. For example, if there is retail on the ground floor of a residential building, we consider it a building that includes both residential and commercial functions. While performing the land-use mix analysis, the 'gas station' and 'construction' legends combined with the 'other' legend from determined land uses. In the last stage, land-use mix analysis was made by considering eight land uses: residential, residential mix-use, non-residential mix-use, education, traditional commerce, private commerce, public institution, and other.

The following formula from Frank et al. (2006) was used for land-use mix analysis;

Land-use Mix = $[(-1) \times [(b1/a) \times \ln(b1/a) + (b2/a) \times \ln(b2/a) + (b3/a) \times \ln(b3/a) + (\ldots) + (b8/a) \times \ln(b8/a)] / \ln 8$

in which;

a refers to the total square meter of land for all eight land uses present in the studied regions, and *b* refers to the square meter of building floor area in each land use

When the results of the land-use mix analysis are examined, it is seen that the Mamak region has the lowest land-use mix ratio, followed by the Sincan and Çankaya periphery regions.

As expected, the highest land-use mix ratio is seen in the Çankaya central region (*0.59*). In this region, the main streets serve the whole of Ankara, such as Tunalı Hilmi, Esat, Tunus, and Bestekar streets. On the contrary, although, surprisingly, the lowest land-use mix ratio has been reached in the Mamak region (*0.47*), this can be explained by the fact that Mamak is mainly used as a residential area despite its central location.

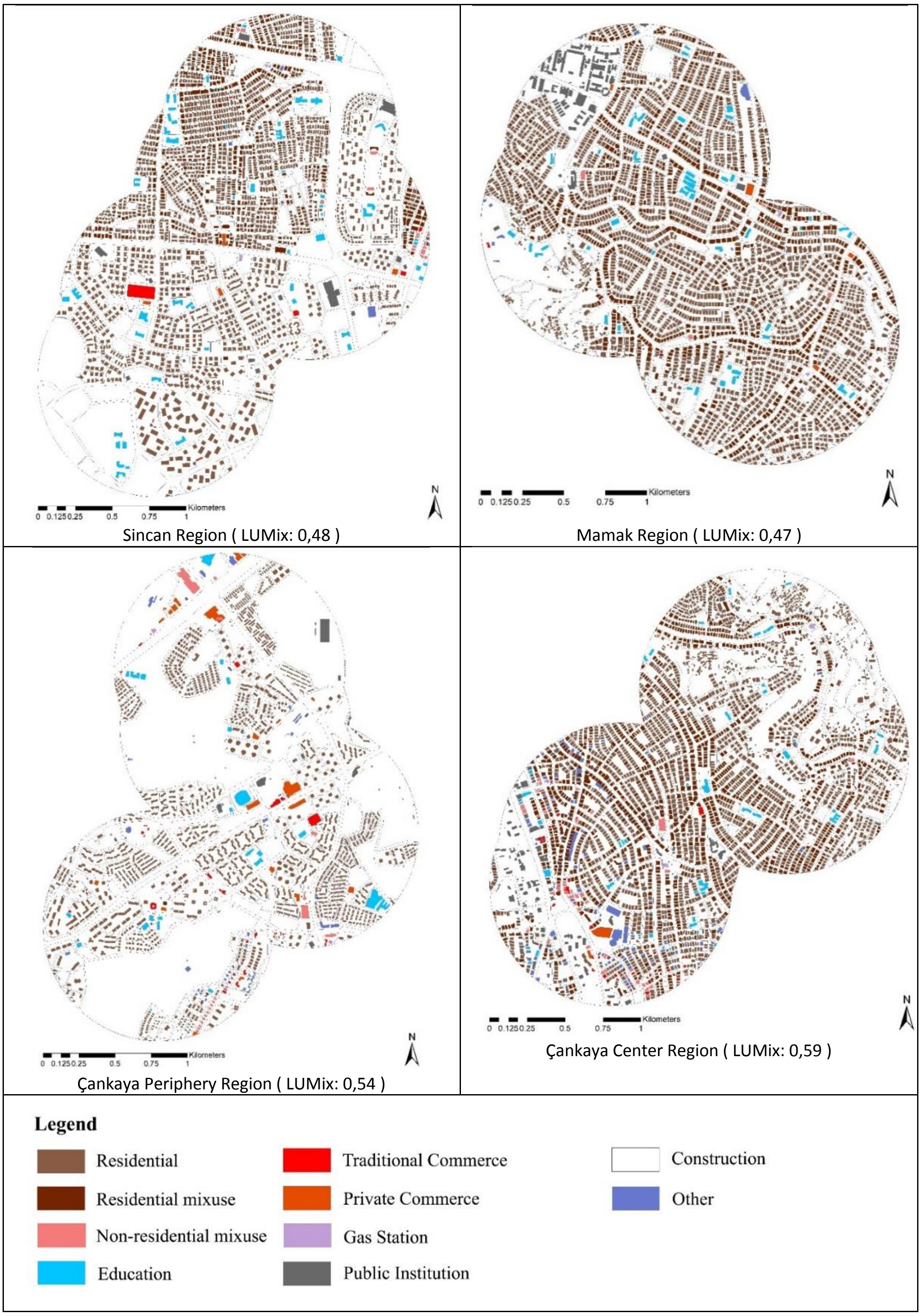


Figure 29. Land-use Mix Analysis of the Regions

3.4.1.6 Open and Green System Analysis

The analysis of open and green systems was crucial to this research because it is well-known that green areas (trees) have a significant impact on air pollution. Green area and air quality connections in the literature were often made using NDVI (Normalized Difference Vegetation Index) calculated from satellite images (Gajjar et al., 2021; Zhan et al., 2018). NDVI is formulated based on the colors reflected from the earth to the satellite. Within the scope of this thesis, however, it was thought that the satellite images would not yield precise results at the studied scale. When the satellite images are analyzed by software like ArcGIS, gardens of the buildings and road medians cannot be distinguished from the built-up areas. Thus, when researchers aim to identify the greenness index of neighborhoods, NDVI analysis cannot give them accurate results, especially in the context of many home gardens, pocket parks, or similar small-scale green areas. Similarly, since NDVI analysis considers the colors reflected from the earth, green-color roof systems cause a bias in the results. In short, the author argues that evaluating the open and green system using up-to-date data from field observations would be more accurate in a study focusing on mesoscale urban form variables.

To the best of the author's knowledge, there is no formula related to open and green system analysis in the literature other than the ones used for calculating the NDVI. In this thesis, three different formulas were used for open and green system analysis: Active Open Green Ratio (AOGR), Active and Passive Green Ratio (APOGR), and Park Ratio (PR) (Figure 30). All of these formulas illustrate the greenness level of a neighborhood from different perspectives.

The following formula was used while calculating the AOGR;

[Total area of building blocks – (Total area of Solid spaces + Total area of hard surfaces + Total area of undesignated places)] / Area of studied regions defined by 800m radius neighborhoods

Compared to the other methods used for analyzing the open and green spaces in the neighborhood, this formula provides a result that more or less informs the author about the size/existence of the building gardens in a neighborhood. In addition, during the fieldwork, it was noted whether the buildings had gardens or not, and this information was transferred to ArcGIS. As a result, it is seen that most of the houses have gardens in the study areas, as seen in Table 6.

Table 6. Buildings with gardens in each studied region

	Number of buildings with garden	**Total number of buildings**	**/**
Sincan Region	2257	2662	0,85
Mamak Region	2956	3680	0,80
Çankaya Periphery Region	2656	2660	1,00
Çankaya Center Region	3054	4014	0,76

While calculating APOGR, the following formula was used:

[Total area of building blocks – (Total area of Solid spaces + Total area of hard surfaces)] + the area of medians / Area of studied regions defined by 800m radius neighborhoods

The aim of the researcher in constructing this formula is to determine the soft/soil spaces in all studied regions. Rather than solid areas (constructions), hard surfaces like car-parking areas are also excluded from this formula. Although it does not show the characteristics of an active green area, undesignated areas that contain only a few trees or bushes and medians were taken into account, and the ratio of the total active and passive green areas to the whole area was found with this formula.

The last formula focuses on the parks that are used for recreational purposes. The formula calculates the ratio of parking areas to the area of studied regions.

Sincan Region

Mamak Region

AOGR: 0,393	APOGR: 0,53	PR: 0,06	AOGR: 0,453	APOGR: 0,462	PR: 0,05

Çankaya Periphery Region

Çankaya Center Region

AOGR: 0,434	APOGR: 0,682	PR: 0,13	AOGR: 0,495	APOGR: 0,499	PR: 0,02

Legend

Hard Surfaces

Soft Surfaces

- Passive open spaces
- Active open spaces
  - Building gardens and undeveloped lands
  - Parks

Figure 30. Open and Green System Analysis of the Regions

When open and green system analyses are examined, the highest AOGR rate is seen in the Çankaya center region (*0.495*), while the lowest is in the Sincan region (*0.393*). When the APOGR rates are concerned, it is seen that the highest value is seen in the Çanlaya periphery region (*0.682*), followed by the Sincan region (*0.53*). As can be seen from Figure 26, the reason for the significant difference between the AOG and APOG ratios in the outlying neighborhoods is the large number of undesignated areas. When we look at the central regions, it is seen that the difference between these rates is minimal. When the PR rate is examined, the highest rate is seen in the Çankaya periphery region (*0.13*), and the lowest rate is seen in the Çankaya center region (*0.02*).

3.4.1.7 Proximity to Industrial Areas

The initial step in this analysis was to create a map in the ArcGIS of the organized industrial zones, marble industries, and sugar factory in the city that may impact the air quality of the regions studied in this thesis (Figure 31). The areas drew as polygon data.

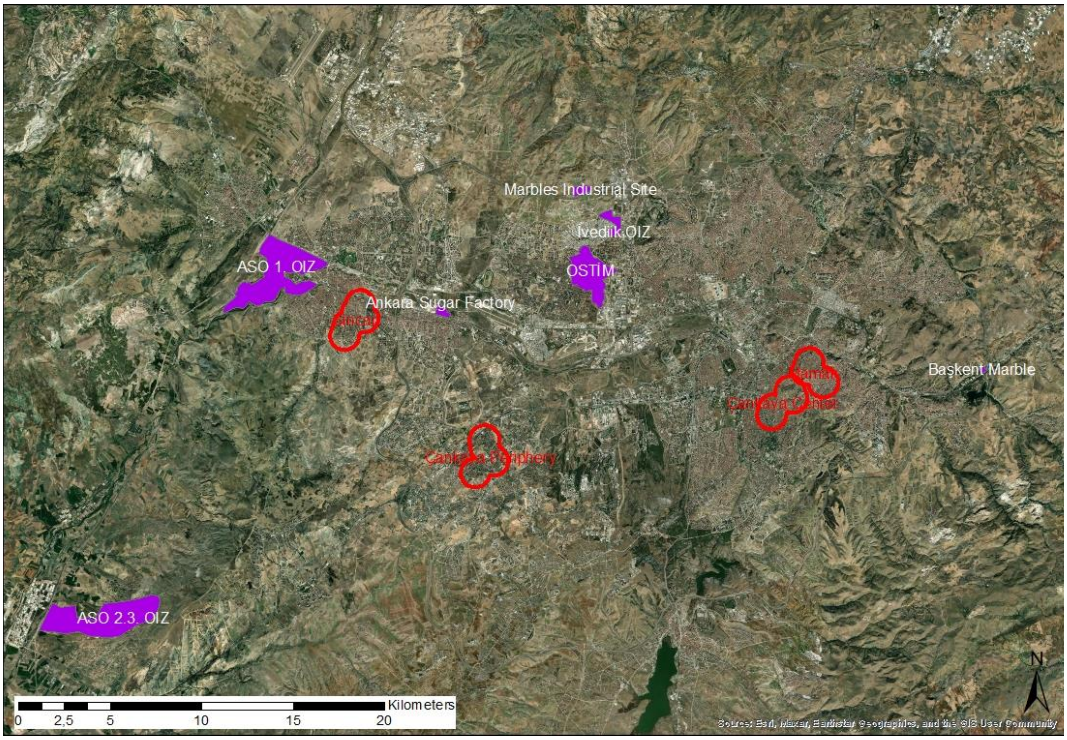


Figure 31. The industrial areas around the studied regions

Each region's midpoint and the midpoint of the industrial zones are marked with a single point. The distance between these points was calculated in km in ArcGIS software. The distance of the two closest industrial areas to each region is taken as a basis in this thesis (Table 7). This analysis was made on a regional basis and was not included in any point-based analyses.

Table 7. Regions’ proximity to industrial areas

	ASO 1 OIZ	Sugar Factory	OSTİM	Başkent Marble
Sincan Region	4,82	4,75		
Mamak Region			13,68	9,11
Çankaya Periphery Region		8,45	11,26	
Çankaya Center Region			12,57	11,05

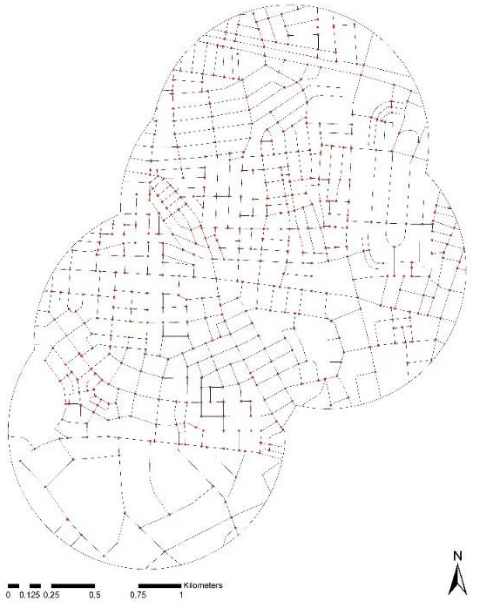
It is seen that the Sincan region is very close to ASO 1 OIZ (*4.82*) and Sugar Factory (*4.75*). It is seen that the most distant region to the industrial areas is the Çankaya Center region (11.05 km to Başkent Marble and 12.57 km to OSTİM).

3.4.1.8 Street Connectivity Analysis

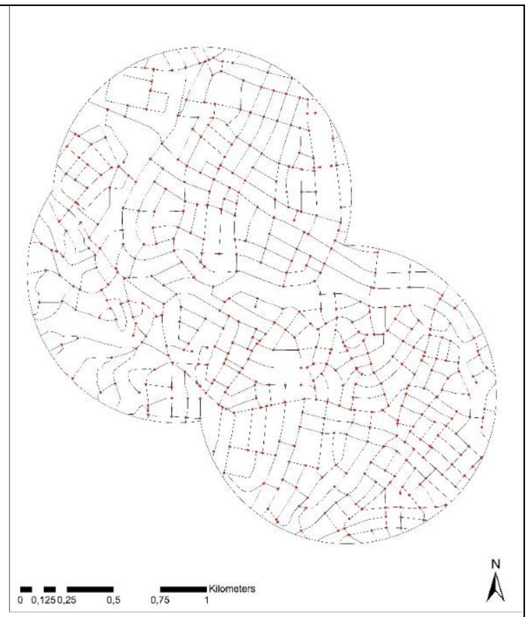
Street connectivity analysis was carried out by calculating the density of the intersection points of the roads in all regions. The formula used for the analysis is as follows:

Number of nodes (intersections) / Area of region (km²)

To increase the validity of the findings, during the calculation, the author ensured that cul-de-sacs and nodes on the 800 m circular buffers of the neighborhoods (the software perceives the border line as a street) were not included in the calculation.

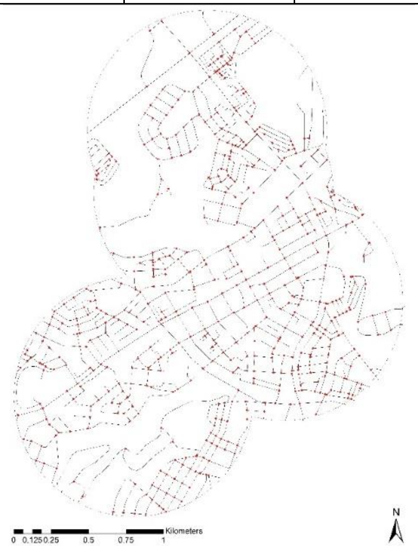


Sincan Region

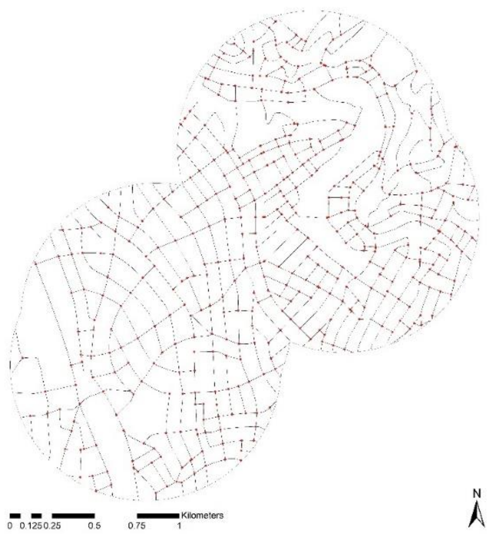


Mamak Region

Number of Nodes: 544	Area of Region (km2): 5,54	Intersection Density: 98,19	Number of Nodes: 498	Area of Region (km2): 4,32	Intersection Density: 115,28



Çankaya Periphery Region



Çankaya Center Region

Number of Nodes: 566	Area of Region (km2): 5,65	Intersection Density: 100,18	Number of Nodes: 459	Area of Region (km2): 4,93	Intersection Density: 93,10

Figure 32. Street Connectivity Analysis of Regions

When the analysis results are examined, it is seen that the area with the lowest intersection density ratio is the Çankaya Center Region, and the area with the highest intersection density ratio is the Mamak Region. When the reasons for the low level of street connectivity in the Çankaya central region are examined, the building blocks in the region are large, and the uses that cover large areas, such as embassies, are located in the region. The reason why the intersection density in the peripheral regions is higher than in the Çankaya center region can be explained by the very small-sized building blocks, as seen in Figure 32.

3.4.1.9 Traffic Volume Analysis

The Yandex Maps was used to extract traffic volume data, as was described in the Data Collection section. Screenshots were taken from this application hourly for the days the author monitored the PM values in the chosen neighborhoods. The traffic data of these images were processed into the attribute table of the roads in the ArcGIS database. The roads were partitioned depending on the color change in the traffic. Traffic flow was entered into ArcGIS as a categorical variable with low, medium, and high-traffic flow categories, just as represented in Yandex maps with the colors green, orange, and red, respectively. Each road was divided according to the colors it took for each hour, and traffic volume information was processed on the attribute tables. The traffic volume data (length of the roads that have traffic data in meters) for different hours of the different days on which the measurement was taken can be seen in Appendix C, Table C.3 – C4.

After this stage, traffic volume data was created for 3 hours per measurement day. Then, the arithmetic average of the road lengths with different traffic volume levels was calculated for each region. The average meter of the roads with high, medium, and low traffic in the regions was obtained. At the last stage, the average distance meter data is divided by the area of the regions, and this data is used as the traffic volume ratio of the regions (see Appendix C, Table C.4). Figure 33 illustrates the traffic volume in the four regions for particular days and times as an example.

Figure 33. Traffic Volume in regions for particular days and times.

3.4.2 Outdoor Air Quality Analysis

3.4.2.1 Mobile Measurements

When the air quality measurement data was transferred from devices to the computer and refined, the first 2 minutes of the data collection were deleted to guarantee the accuracy and stability of the samples at each measurement. First, air quality measurement points were drawn in ArcGIS (as point data) with a unique ID. By considering the measurement time information (in minutes) at the air quality measurement points, the arithmetic average value for stopped time in each point was calculated and transferred to the ArcGIS environment by labeling them according to date and time. The base maps used during the fieldwork and the database created can be seen in Appendix D.

In studies using multi-point sampling, some studies use interpolation to convert the point data of pollutant concentrations to area data in order to represent the study area (Beauchamp et al., 2017; Gao et al., 2019), studies that generalize the point data to the 50m area data by taking the mean values of the point data of pollutant concentrations (C. Zhang et al., 2022), or studies that analyze the city form components in the area formed by putting a buffer around these points after collecting point data (Liu et al., 2021). In this thesis, both the Kriging and buffer method is used.

In order to answer the second research question of the thesis, point-based PM concentrations were interpolated. The point data was converted to area data to compare with the health data obtained on a regional basis. PM values were modeled using Ordinary Kriging, which is the most frequently used method in the literature (Beauchamp et al., 2017; Kurkcuoglu & Zengin, 2021). Different semivariogram models were adopted depending on the PM10 and PM2,5 concentration values for each measurement day. While selecting the semivariogram models, ME, RMSE, SME, RMStdE, and ASE values were considered as described in the Slope analysis part. Air quality interpolation models of all days measured in the regions are shown in Figure 34. In the Figure, the modeling of the measurements taken on which date, which semivariogram model was used, and the Min, Max, Mean, and SD values for each measurement day can be seen.

When the regions' PM2,5 concentrations are compared, it can be noted that the Mamak region had both the highest (*501.99*) and lowest (*5.43*) values that have been measured. In fact, this situation shows that there are significant differences between pollutant concentrations even though they are in the same region when looked at on a point basis.

In addition, when each region is examined in terms of PM2,5 concentrations, results show that:

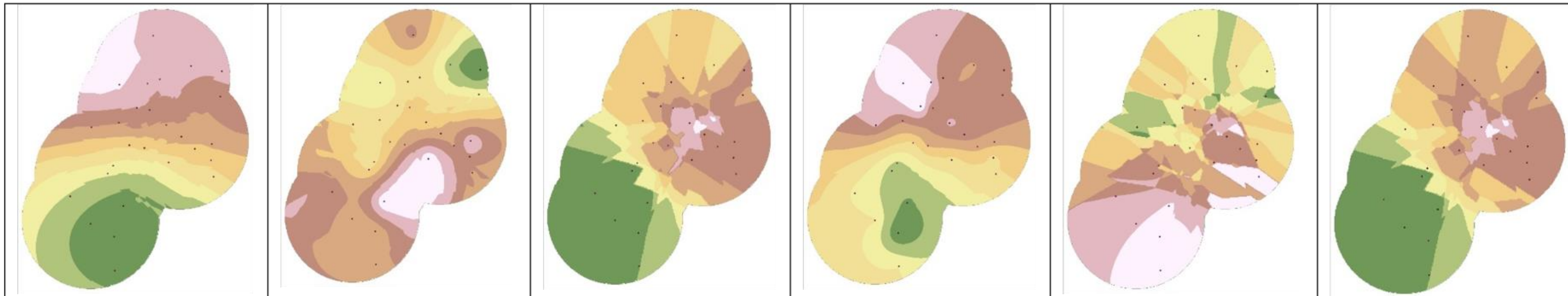
- The concentration values in the Sincan region are not concentrated in a particular area and differ for each measurement day.

-For every three days of measurement in the Mamak region, the pollutant concentrations are concentrated in the northern parts of the region. There are fewer pollutant concentrations in the southern parts compared to the north.

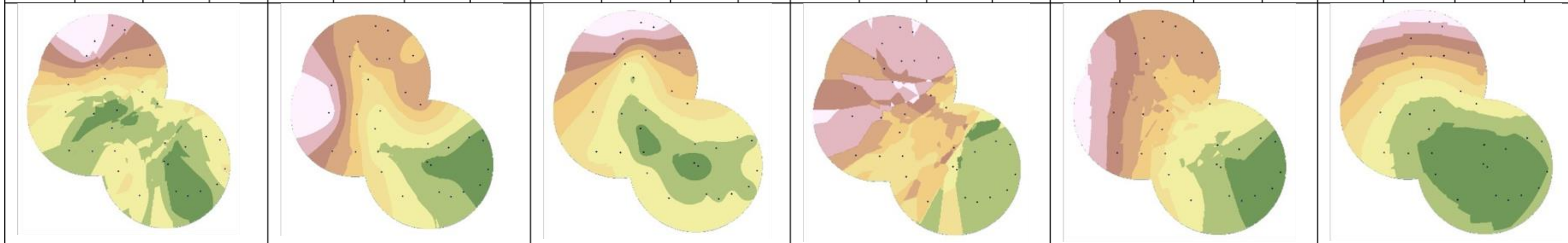
- The pollutant concentrations in the Çankaya Periphery region are concentrated in the northern parts of the region.

- While the concentrations of pollutants in the northern parts are concentrated in the measurements taken on weekdays in the Çankaya Center region, the concentrations in the southern parts are more intense in the measurement taken on Sunday. In the south of the Çankaya center region, some streets are used very intensively, especially on weekends, and this region shows the characteristics of a sub-center throughout Ankara.

The distribution of PM10 concentrations in the regions approximately coincides with PM2,5 concentrations. The point where PM10 concentration is measured the most is in the Mamak region (*372.3*), while the lowest measurement point is in the Sincan region (*28.89*).

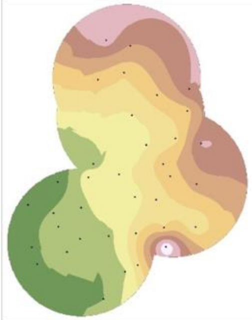


Panel	Min:	Max:	Mean:	SD:
Sincan PM2,5 – 09.11.21 (Gaussian)	178,28	270,58	222,57	27,77
Sincan PM2,5 – 11.11.21 (Circular)	22,48	46,65	36,26	4,83
Sincan PM2,5 – 14.11.21 (Gaussian)	171,43	201,5	183,53	7,7
Sincan PM10 – 09.11.21 (Exponential)	163,99	278,96	224,97	27,82
Sincan PM10 – 11.11.21 (Spherical)	28,89	34,52	32,14	1,47
Sincan PM10 – 14.11.21 (Gaussian)	167,8	198,05	180,34	8,06



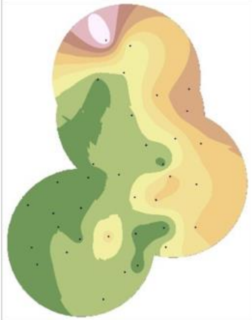
Panel	Min:	Max:	Mean:	SD:
Mamak PM2,5 – 08.11.21 (Exponentiall)	n: 95,51	116,06	102,38	SD: 5
Mamak PM2,5 – 12.11.21 (Spherical)	5,43	121,64	57,62	30,12
Mamak PM2,5 – 13.11.21 (Lİnear)	83,69	501,99	239,23	94,5
Mamak PM10 – 08.11.21 (Spherical)	101,66	121,67	112,23	4,92
Mamak PM10 – 12.11.21 (Gaussian)	66,99	159,13	108,3	23,8
Mamak PM10 – 13.11.21 (Gaussian)	67,63	372,3	157,75	76,97

Figure 34. Ordinary Kriging analysis of each region for each measurement day



Çankaya P. PM2,5 – 03.11.21 (Exponential)

Min:	Max:	Mean:	SD:
43,04	76,79	56,79	7,9

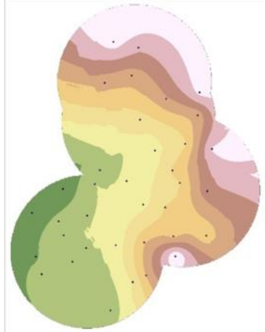


Çankaya Per. PM2,5 – 05.11.21 (Circular)

Min:	Max:	Mean:	SD:
119,68	167,47	133,4	9,88

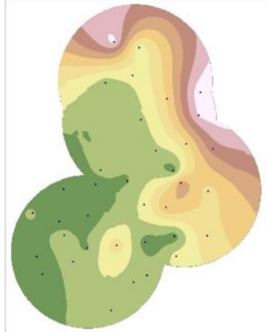
Çankaya Per. PM2,5 – 06.11.21 (Circular)

Min:	Max:	Mean:	SD:
136,39	176,5	159,25	9,6



Çankaya Per. PM10 – 03.11.21 (Spherical)

Min:	Max:	Mean:	SD:
41,5	73,93	56,93	9,16

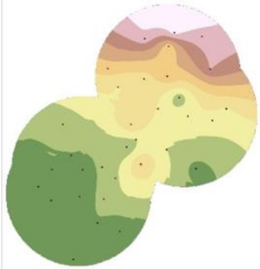


Çankaya Per. PM10 – 05.11.21 (Linear)

Min:	Max:	Mean:	SD:
120,53	173,69	137,84	13,09

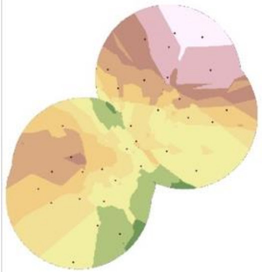
Çankaya Per. PM10 – 06.11.21 (Spherical)

Min:	Max:	Mean:	SD:
133,54	174,49	156,49	9,7



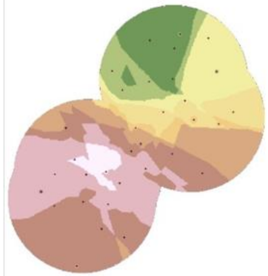
Çankaya Cen. PM2,5 – 02.11.21 (Spherical)

Min:	Max:	Mean:	SD:
27,41	167,16	69,9	35,91



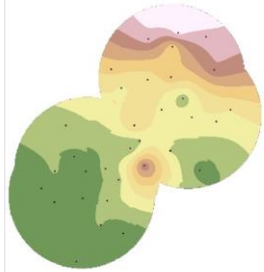
Çankaya Cen. PM2,5 – 04.11.21 (Gaussian)

Min:	Max:	Mean:	SD:
54,15	83,04	68,17	6,4



Çankaya Cen. PM2,5 – 07.11.21 (Exponential)

Min:	Max:	Mean:	SD:
57,74	103,19	82,23	12,42

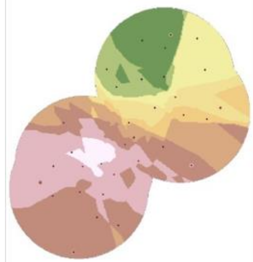


Çankaya Cen. PM10 – 02.11.21 (Spherical)

Min:	Max:	Mean:	SD:
30,43	166,45	72,98	34,59

Çankaya Cen. PM10 – 04.11.21 (Spherical)

Min:	Max:	Mean:	SD:
55,17	100,16	73,13	11,08



Çankaya Cen. PM10 – 07.11.21 (Exponential)

Min:	Max:	Mean:	SD:
55,72	101,56	80,97	12,23

Legend

Figure 34 Continued

In addition to considering air quality data at the regional level, a point-based approach has also been used. The reason for performing this method is that measurements taken within the same neighborhood show differences, as we can clearly see in the Mamak region. That's why it is desired to interpret these differences on a point basis rather than generalize and interpret them on a neighborhood basis. To answer the first research question asked within the scope of the thesis, a comparison of PM concentrations with urban environment variables was made on a point-based basis. Buffers of 100, 150, and 200 meters were placed around the points where each air quality measurement was taken, and the urban environment variables in these buffers were calculated and compared.

While performing buffer analysis, if the boundaries of the buffers are outside the analyzed boundaries, these buffers are clipped, and the analyzed boundaries are adhered to. This is because the analysis will give errors if the areas where there is no data are included in the calculation. In this context, 19 buffers from 200 m, 12 buffers from 150 m, and three buffers from 100 m were clipped. The areas covered by the buffers can be seen in Figure 35.

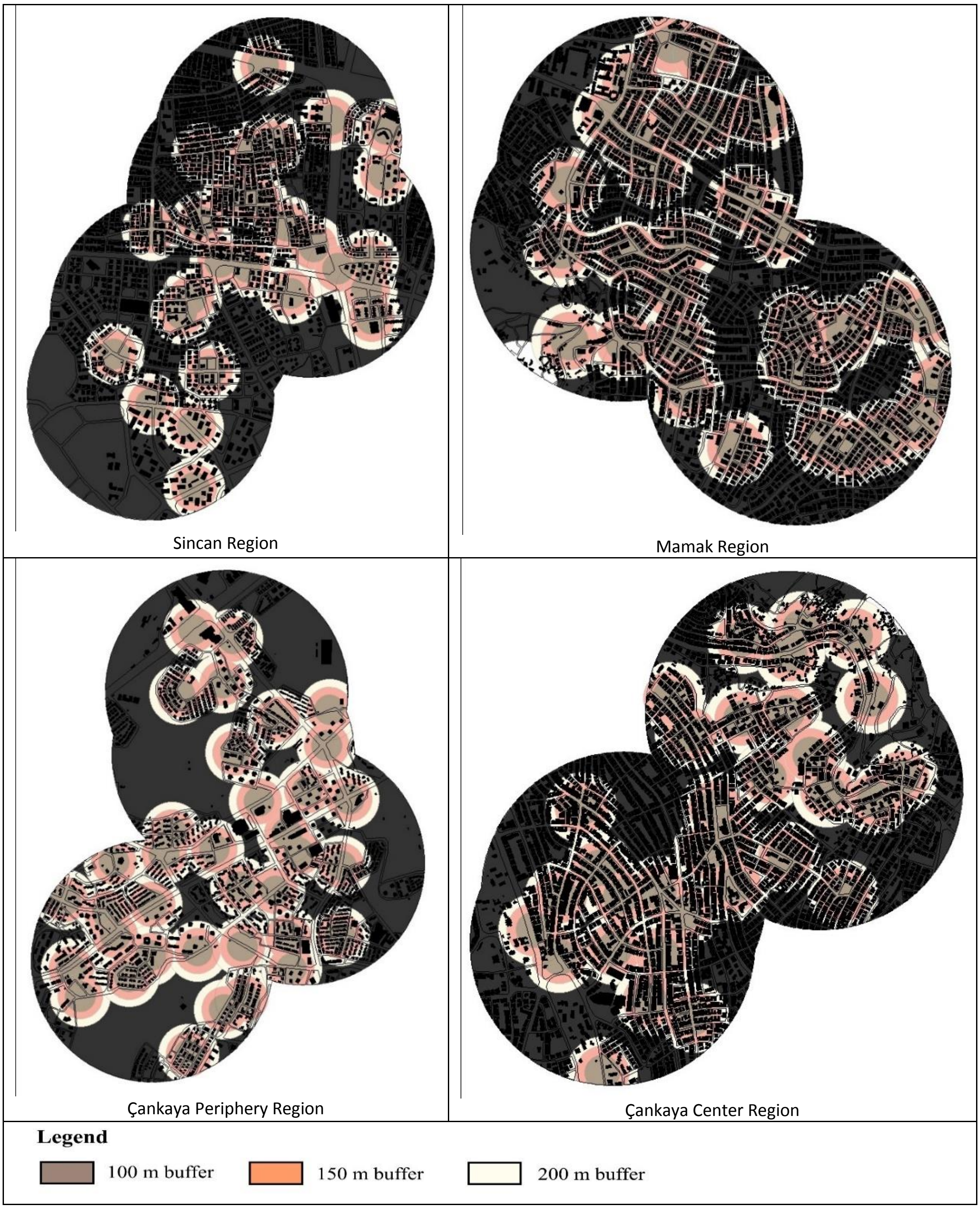


Figure 35. Buffers created around each measurement points

After the buffers were drawn, the following steps were followed to calculate the urban environment variables remaining in the buffers;

1. From the interpolated slope data, Z values were transferred to the air quality measurement points. For this, “ArcToolbox > 3D Analyst Tool > Functional surface > Add Surface Information” steps have been followed.
2. From the interpolated temperature, relative humidity, and wind speed raster data values were transferred to the air quality measurement points. For this, “ArcToolbox > Spatial Analyst Tool > Extract Values to Points” steps have been followed.
3. From Figure-Ground and Building Density analysis, the areas of solid spaces within buffer zones are calculated using the Spatial Join tool in ArcGIS. Before using the Spatial Join tool, the solid spaces were split using the Split tool. This is because the researcher wanted to take into account solid areas cut by buffers. “ArcToolbox > Analysis Tools > Overlay > Spatial Join” steps have been followed for the analysis.
4. For extracting Land-use data within buffers for each land-use Spatial Join tool has been used.
5. To calculate Open and Green System analysis for each buffer, first, the Split tool and then the Spatial Join tool was used for each land use needed in the calculations.
6. For Street Connectivity analysis, nodes within each buffer were calculated with the Spatial Join tool.
7. To calculate road meters for every day in each buffer, the Split tool and Spatial Join tool were used in Traffic Analysis.

3.4.2.2 24-hour Measurements

In the 24-hour point measurements, as mentioned in the data collection section, measurements were taken simultaneously in a central and peripheral neighborhood. Analysis of 24-hour measurements was made by first converting minute data to hourly data. The corresponding average PM2.5 and PM10 mass concentrations were calculated by taking the arithmetic average of all the minute samples recorded by the monitor. Then the graphs are created for each measurement day. Thus, the changes in the central and peripheral neighborhoods were compared.

As is mentioned under the Data Collection title, on 22.11.2021, one of the devices was placed in Sincan Primary School (SN2), and one in 75. Yıl Primary School (MN3), on 23.11.2021, the devices were placed in Sincan İMKB (SN4) and Abidinpaşa (MN1) Primary Schools, on 24.11.2021, the devices were placed in Avni Akyol (CPN4), and Teğmen Kalmaz (CN4) primary schools, lastly on 25.11.2021, the devices were placed in Mimar Sinan Secondary School (CN1), and in an apartment opposite to Münevver Öztürk Secondary School (CPN2). The graphs prepared for each measurement day can be seen in Figures 36 and 37.

Considering the measurements in the Sincan and Mamak regions, it is seen that the graph lines run approximately parallel. However, it is seen that very high values were measured between 11:28 and 14:28 in the Sincan region on 23.11.21.

When the measurements taken from Çankaya Periphery and Çankaya Center regions are comparatively examined, we can see that the air quality around the schools in the Çankaya Center region is worse. While fluctuations in pollutant concentrations are also observed in the Çankaya center region, it is observed that the concentrations in the Çankaya Peripheral region follow a more stable trend. One of the reasons why there are no fluctuations in PM2.5 concentrations in the Çankaya Periphery region could be that green areas surround the schools in that region. None of the schools in other regions have green areas surrounding the schools.

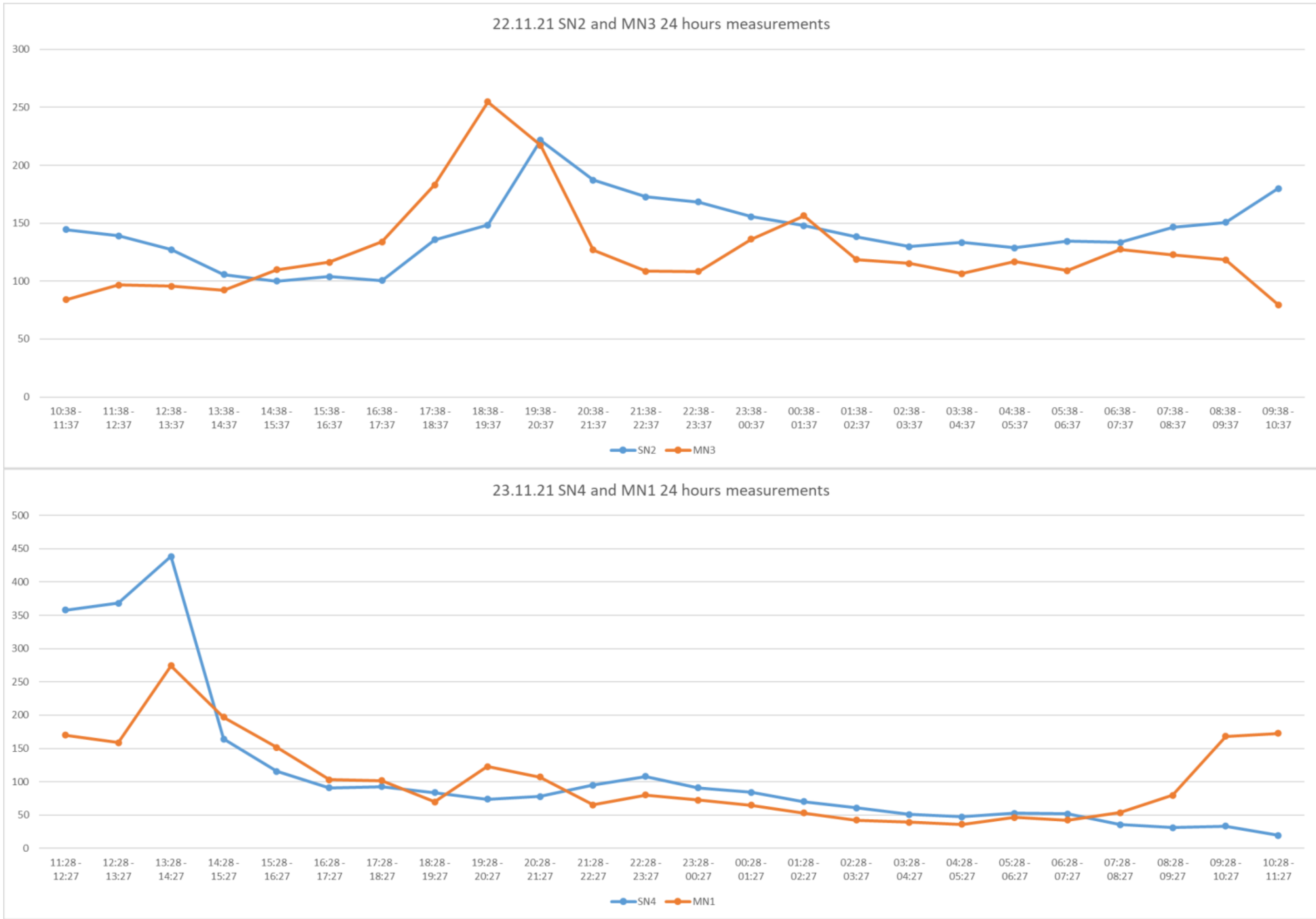


Figure 36. 24-hour measurements in Sincan and Mamak Regions

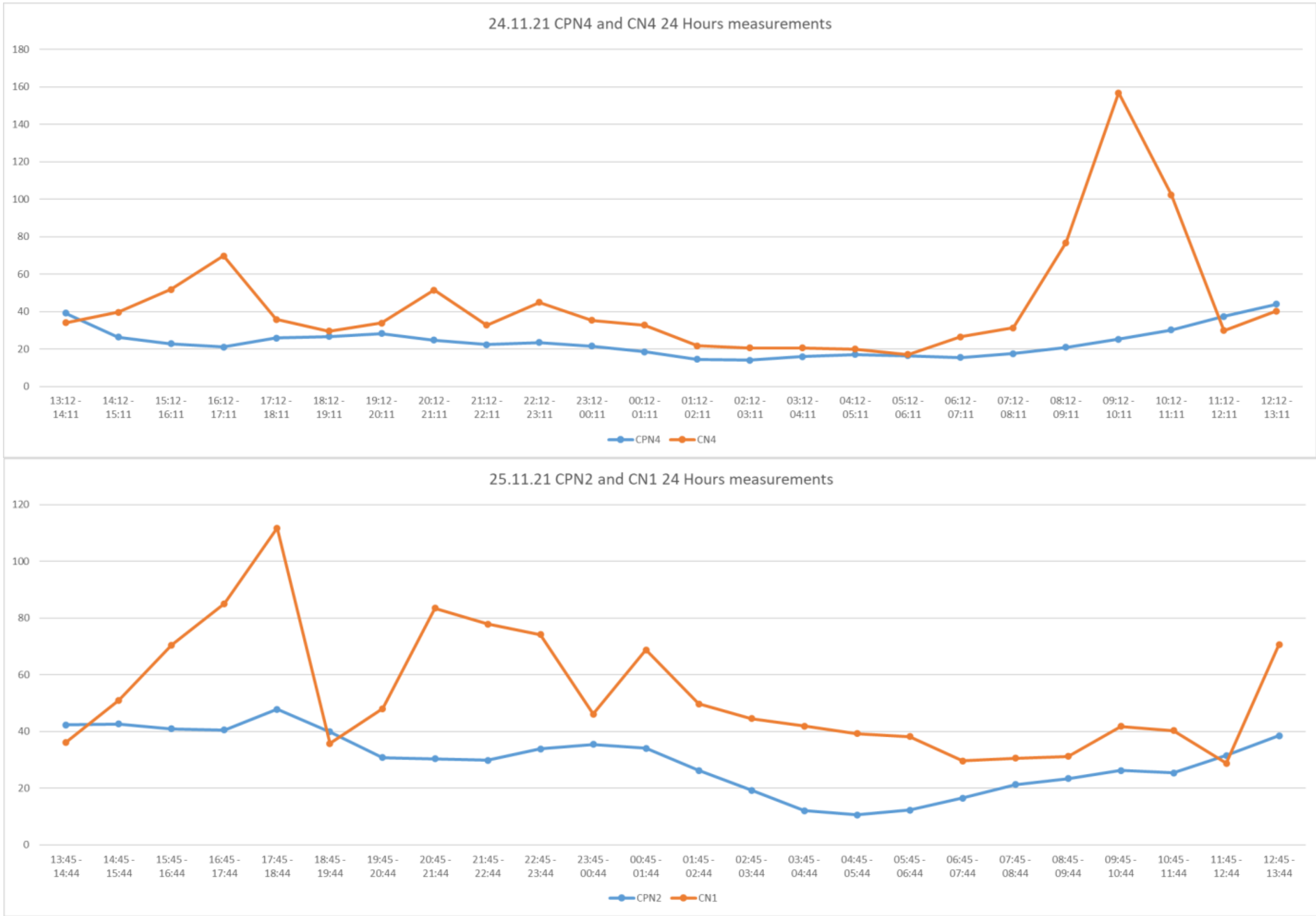


Figure 37. 24-hour measurements in Çankaya Center and Çankaya Periphery Regions

3.4.3 Analysis of Health Data

The health data obtained from the Ministry of Health was refined according to ages and districts. While analyzing the health data, by focusing on 7-to-12-year-old children, the total number of children with doctor-diagnosed asthma and the number of children registered to a health center were closely examined (Table 8). It is seen from the table that Mamak and Sincan are dense areas in the context of the child population compared to other regions.

Table 8. 7-12 aged children with physician-diagnosed asthma in regions

District	Name of Family Public Health Center	7_12 aged physician diagnosed children	7_12 aged total children	%
MAMAK	ABİDİNPAŞA DR. EMRE DEMİR FPHC	88	2478	3,551251009
MAMAK	MUTLU FPHC	198	2797	7,079013228
MAMAK	TUZLUÇAYIR FPHC	189	3908	4,836233367
MAMAK	VELİ GÜNDÜZ ŞAHİN FPHC	188	4441	4,233280793
MAMAK	ÜMMÜ GÜLSÜM GÜÇLÜOĞLU FPHC	172	3204	5,368289638
MAMAK	MAMAK TOTAL	835	16828	4,961968148
SİNCAN	TURGUT REİS FPHC	18	714	2,521008403
SİNCAN	SİNCAN 1 NO FPHC	148	4705	3,145589798
SİNCAN	SİNCAN 11 NO FPHC	110	1456	7,554945055
SİNCAN	SİNCAN 6 NO FPHC	119	3026	3,93258427
SİNCAN	SİNCAN 9 NO FPHC	91	3016	3,017241379
SİNCAN	MEHMET-NURHAN KAYNAK FPHC	278	6725	4,133828996
SİNCAN	OSMANLI FPHC	211	4097	5,150109836
SİNCAN	SİNCAN TOTAL	975	23739	4,107165424
ÇANKAYA	BESTEKAR FPHC	35	510	6,862745098
ÇANKAYA	GAZİ OSMAN PAŞA FPHC	39	418	9,330143541
ÇANKAYA	HOŞDERE FPHC	14	473	2,959830867
ÇANKAYA	TINAZTEPE FPHC	37	820	4,512195122
ÇANKAYA	İNCESU FPHC	34	1003	3,389830508
ÇANKAYA	ÇANKAYA CENTER TOTAL	159	3224	4,931761787
ÇANKAYA	ÇAYYOLU 1 NO FPHC	75	1937	3,871966959
ÇANKAYA	ÇAYYOLU 2 NO AYŞE ANA FPHC	45	1583	2,842703727
ÇANKAYA	ÇAYYOLU 3 NO FPHC	65	1584	4,103535354
ÇANKAYA	ÇANKAYA PERİPHERY TOTAL	185	5104	3,62460815

The percentage of children with asthma was determined for each region by dividing the number of children with doctor-diagnosed asthma by the total number of registered children in each region. The highest percentage of children with doctor-diagnosed asthma are in the central regions (Mamak: 4.96, Çankaya Center: 4.93). The highest number of children with physician-diagnosed asthma is in the Sincan region (975 children). The lowest asthma rate is seen in the Çankaya periphery region (3.62).

Physician-diagnosed asthma data has been used in many studies in the literature that look for the relationship between urban environment and childhood asthma (English et al., 1999; Portnov et al., 2012; Spira-Cohen et al., 2010; Zmirou et al., 2004).

In studies that link doctor-diagnosed asthma and urban environment data;

-either the children who are sick were handled as cases and the environments they lived in were examined (English et al., 1999),

- either the rates of asthma differing on urban-rural basis were handled and compared with urban characteristics (Pesek et al., 2010),

-or comparisons were made over the number of applications to hospital emergency departments and focused on the hotspots in terms of asthma (Corburn et al., 2006).

Therefore, while making comparisons within the scope of this thesis, both the number of patients in the regions and asthma ratios were used and discussed with urban environment caharacteristics.

Since the health data could not be obtained on an address basis, it was not possible to spatialize the data and compare it with point-based urban environmental components and air quality data. Since the health data is region-wide, it was compared with the urban environment and air pollution data on a regional basis. The answers to the 2nd and 3rd research questions asked within the scope of this thesis were therefore discussed and evaluated for four regions.

3.4.4 Analyzing the Relationships between the Urban Environment, Outdoor Air Quality and Childhood Asthma

The relationship between the urban environment and outdoor air quality has been investigated in two different ways. The first investigation is based on points, while the second is based on regions. As it was mentioned under the heading "Outdoor Air Quality Analysis," point-based analyses were done by calculating the urban form variables in the region covered within the 100, 150, and 200 m buffers which were drawn around each air quality measurement spot.

To answer the first question of the research, ‘What is the relationship between mesoscale urban environment characteristics and outdoor air quality?’, Pearson Product-Moment Correlation is used. With this method, the researcher aimed to understand whether there is a correlation between urban environmental values and PM10 and PM2.5 concentrations, and if there is a correlation, whether this correlation is positive or negative. Correlation coefficients provide a numerical summary of the direction and the strength of the linear relationship between two variables. The Pearson product-moment correlation coefficient, r, is easily the most frequently used measure of association and the basis of many multivariate calculations (Tabachnick & Fidell, 2013). Regional-based comparisons were also made under this question.

Prior to each SPSS analysis, all data were normalized between 0 and 1. Since there are so many data and there is a significant difference between them, it was best to deal with the data in a single order.

The data sets used to answer first research question are;

-Mobile air quality measurement data

-Natural environment data assigned to each air quality measurement point

-The built environment data of the area within the 100, 150, and 200 m buffers thrown around each air quality measurement point.

-Urban environment analysis results in each region

-Mobile measurement values for each region

- 24 hours measurement values for each region

The first sub-question of the first main research question is as follows:

1.a. Which features of the urban environment significantly affect outdoor air quality?

After analyzing the correlation coefficients, a single variable linear regression was utilized to examine the factors that were significantly correlated with PM10 and

PM2.5 concentrations. This helped the author to understand how many unit changes in PM concentrations could be explained with a one-unit change in each urban environmental variable. As stated by Tabachnick & Fidell (2013), regression is used to forecast a score on one variable based on a score on another, whereas correlation is used to quantify the strength and direction of the linear relationship between two variables.

The second sub-question of the first question of the research is:

1.b. Do urban spots with less or more air pollution show a differentiation based on the urban environment characteristics of their surroundings?

To respond this sub-research question, the *independent sample t-test* was used between 20 urban spots with the highest and 20 urban spots with the lowest PM10 and PM2.5 values. The aim was to understand whether the urban spots with more or less air pollution differ according to their urban environmental characteristics. Independent-samples t-test is a test used to compare the mean scores of two different groups of variables (Cohen, 1988). From each PM concentration value, min 20 and max 20 were labeled, and then the researcher utilized an independent sample t-test to compare the means of these two groups.

The second main research question is about the relationship between outdoor air quality and childhood asthma: 'Is there a relationship between urban environment-caused outdoor air pollution and childhood asthma?' The data sets used to understand the relationship between outdoor air quality and childhood asthma are;

-Mobile measurement values for each region

- 24 hours measurement values for each region

-Physician-diagnosed asthma rates in regions studied.

-Number of children aged between 7-12 that diagnosed with asthma in regions.

The first sub-question of this second question is as follows:

2.a. Are children diagnosed with asthma living in environments with more intense air pollution?

Since the asthma data obtained from the Ministry is region-based (i.e., the author assumes that children whose data were analyzed live in and near the selected regions), the asthmic status of children were compared among the four chosen regions. The values received by each region were compared, and the relationship between outdoor air quality and childhood asthma was defined accordingly. Both mobile PM10 and PM2.5 measurements taken from regions and 24-hour PM2.5 measurements taken from schools were used as air quality data. First, a single data was obtained by taking the data's arithmetic average for three days in mobile measurements and generalizing it to the region with the kriging method. For 24h measurements, the arithmetic average of the measurements for each region was accepted for the region. The results of these analyses are shown in Table 9. The table shows that the data obtained from the mobile measurements and 24-hour measurements are consistent in all regions except the Çankaya Periphery Region. This situation indicates that there are serious differences between the pollutant concentrations measured on the roads and the pollutant concentrations measured in the schools in the Çankaya Periphery Region. As stated in the previous sections, it was only in Çankaya Periphery region where the author obtained the 24 hour measurements from the balcony of a residential building. The author assumes that two factors might have affected the results obtained in the Çankaya Periphery Region regarding the PM2.5 and PM10 valurs. The first one could be related to the heights at which the measurements were taken. As the previous research has shown, greater altitudes at the same location had less air pollution (Warlina et al., 2019). While the mobile measurements taken by car were taken from a height of 1.1 m, one of the measurements taken at schools in the Çankaya Periphery Region was taken from a height of approximately 13 m and the other from a height of approximately 21 m. The second one could be related to the location of the measurements. It is important to note that all of the 24h measurements were taken inside highly vegetated areas (e.g., a balcony inside a gated community with large green spaces and a school building which is located in front of a forested area). However, further research should be done to find out the reasons behind these differences.

Table 9. PM10 and PM2.5 values obtained from the mobile and 24h measurements in the chosen regions

	Mean of PM10 Concentrations in Mobile Measurements	24h Measurements
Sincan	145,82	
Mamak	126,09	
Çankaya Periphery	116,48	
Çankaya Center	75,69	
	Mean of PM2.5 Concentrations in Mobile Measurements	PM2,5_µg/m³
Sincan	147,45	127,72
Mamak	133,08	114,72
Çankaya Periphery	117,09	26,70
Çankaya Center	73,43	48,56

The third main research question of this thesis is about the relationship between urban environment and childhood asthma. More specifically, it asked: ‘ What are the physical characteristics of the neighborhoods where children are more prone to asthma?’. Under this research question, one sub-research question is posed:

3.a. Which urban environment characteristics at the neighborhood scale play a role in promoting childhood asthma?

To respond this sub-research question, the comparison of the urban environment data and health data was made on a regional scale. Firstly, the air-quality-measurement-day-based meteorological data and traffic data was refined by taking their means in each region. Then all of the urban environmental characteristics (natural and built) of regions and health data (numbers and ratios) were compared to answer the 3rd research question and its sub-question of the thesis. The data sets used to understand the relationship between the urban environment and childhood asthma are;

-Urban environment analysis results in each region

-Physician-diagnosed asthma rates in regions studied.

-Number of children aged between 7-12 that diagnosed with asthma in regions.

3.5 Concluding Remarks

Table 10 summarizes the data collection methods and analysis used to respond the questions posed in this thesis. The author used both primary and secondary data to respond the research questions. Site excursions to update the plans obtained from the Ankara Metropolitan Municipality and street level air quality monitoring were the two main primary data collection techniques. All other data, including data regarding the asthmic conditions of children and metereological data, were obtained from secondary sources. A variety of geographical and statistical analysis techniques were used to respond each research question of the thesis. The following chapter presents the results for each research question.

Table 10. A summary of the data collection and analysis techniques that were used to respond the research questions posed in this thesis

Research Questions	Data Collection Methods	Data Analysis Methods
1. What is the relationship between mesoscale urban environment	▪ Site excursions ▪ Satellite images	▪ GIS analysis

characteristics and outdoor air quality?	▪ Draft maps obtained from the Ankara Metropolitan Municipality ▪ Street level PM10 and PM2.5 measurements	▪ Pearson Product-Moment Correlation
1.a. Which features of the urban environment significantly affect outdoor air quality?		▪ GIS analysis ▪ Linear regression
1.b. Do urban spots with less or more air pollution show a differentiation based on the urban environment characteristics of their surroundings?		▪ GIS analysis ▪ Independent sample t test
2. Is there a relationship between urban environment-caused outdoor air pollution and childhood asthma	▪ Street level PM10 and PM2.5 measurements ▪ 24h PM2.5 measurements ▪ Physician diagnosed asthma data obtained from Ministry of Health	▪ GIS analysis
2.a. Are children diagnosed with asthma living in environments with more intense air pollution?		▪ GIS analysis
3. What are the physical characteristics of the neighborhoods where children are more prone to asthma?	▪ Site excursions ▪ Satellite images ▪ Draft maps obtained from the Ankara Metropolitan Municipality ▪ Physician diagnosed asthma data obtained from Ministry of Health	▪ GIS analysis
3.a. Which urban environment characteristics at the neighborhood scale play a role in promoting childhood asthma?		▪ GIS analysis

CHAPTER 4

RESULTS

This chapter presents the results of the study. The chapter is organized under three main sub-chapters, all of which refer to the three major research questions of the thesis. Responses to the sub-research questions of the thesis were given under the related sub-chapters; sub-sub chapters provides the results of these sub-research questions.

4.1 Understanding the Relationship between Urban Environment Characteristics and Outdoor Air Quality

One main and two sub-questions were asked regarding urban environmental characteristics and outdoor air quality. The answers to all questions are presented separately below.

1. What is the relationship between mesoscale urban environment characteristics and outdoor air quality?

Referring to the second chapter of the thesis, features of the urban environment were investigated both for the natural and built environmental features of the selected regions. First, the impacts of natural environment characteristics on PM concentrations were investigated through correlations. Afterward, correlations were made to examine the effects of urban form variables on air quality in buffers of 100, 150 and 200 m.

Table 11 shows the correlations between natural environment characteristics (Altitude = Z values, Wind speed, Relative Humidity and Temperature) and mobile measurements of the regions. Pearson correlations between Z values and PM concentrations show that there is a strong, negative correlation between the variables, *r*=-,488, *n*=128, *p*<0,01 for PM2,5 concentrations and *r*=-,467, *n*=128, *p*<0,01 for PM10 concentrations.

Table 11. Correlation results of natural environment and PM concentrations

	PM2,5	PM10
Altitude	-,488**	-,467**
Wind Speed	0,003	0,078
Relative Humidity	-,493**	-,448**
Temperature	-,606**	-,559**
** p< 0.01 * p< 0.05		

When we look at the relationship between wind speed and PM concentrations, Pearson Product Moment Correlation Coefficient values show no relationship, *r*=,003, *n*=128, *p*>0,05 for PM2,5 concentrations and *r*=,078, *n*=128, *p*>0,05 for PM10 concentrations. Unlike wind speed, other meteorological factors seem to have a strong, negative correlation with PM concentrations. It is seen that the correlation between relative humidity and PM2.5 concentrations is negative and strong (*r*=-,493, *p*<0,01) its correlation with PM10 concentrations (*r*=-,448, *p*<0,01) is also negative and strong. Pearson correlations between temperature and PM concentrations show that there is a strong, negative correlation between the variables, *r*=-,606, *n*=128, *p*<0,01 for PM2,5 concentrations and *r*=-,559, *n*=128, *p*<0,01 for PM10 concentrations.

The link between built urban environment and outdoor quality is investigated for buffers having different radius, from 100 to 200meters. Considering the relationship between built environment characteristics and PM concentrations within 100 m buffers, it is seen that only Figure-Ground and medium traffic values have a negative correlation with PM10 and PM2.5 concentrations (Table 12). When we look at Table

12, in general, we see that the correlations of values other than Street Connectivity, Acvtive and passive green ratio (APOGR), Park Ratio and High Traffic Volume with PM concentrations are negative. Although this is not as significant as Figure-Ground and Medium traffic values, it shows that PM concentrations decrease as Building Density, AOGR (Active Open Green Ratio), Land-Use Mix and Low Traffic Volume values increase. It is also understood that PM concentrations increase as Street Connectivity, APOGR, Park Ratio and High Traffic Volume increases. When we focus on the significant relationships of the Pearson Correlation analysis, it is seen that the relationship between Figure-Ground and PM2.5 concentrations (r=-,259, p<0,01) is approximately 7%, and its relationship with PM10 concentrations (r=-,235 p<0,01) is about 6%. It can be said that Medium Traffic Volume helps us explain about 4% of the variance of PM2.5 concentrations (r=-,198, p< 0.05) and 3% of the variance of PM10 concentrations (r=-,186, p< 0.05).

Table 12. Correlation results of built environment features in 100m buffers and PM concentrations

	PM2,5	PM10
Building Density (r:100m)	-0,118	-0,105
Street Connectivity (r:100m)	0,012	0,022
Figure-Ground (r:100m)	-,259**	-,235**
AOGR (r:100m)	-0,062	-0,088
APOGR (r:100m)	0,076	0,047
Park Ratio (r:100m)	0,163	0,154
Land-Use Mix (r:100m)	-0,132	-0,115
Low traffic volume (r:100m)	-0,115	-0,122
Medium traffic volume (r:100m)	-,198*	-,186*
High traffic volume (r:100m)	0,081	0,078
** p< 0.01 * p< 0.05		

Figure-Ground (*r*=-,192, p< 0.05), Park Ratio (*r*=,181, p< 0.05), Land-Use Mix (*r*=-,222, p< 0.05), Low (*r*=-,196, p< 0.05), and Medium (*r*=-,216, p< 0.05) Traffic Volume values exhibit a strong correlation with PM 2.5 concentrations when the correlations between the urban built environment features and PM concentrations in the 150 m buffers are evaluated. It is observed that Park Ratio shows a positive correlation, while Figure-Ground, Land-Use Mix, Low and Medium Traffic Volume values show a negative correlation. This leads us to conclude that the increase in Park Ratio in the 150 m buffers around each spot causes PM2,5 concentrations to rise.

Table 13. Correlation results of built environment features in 150m buffers and PM concentrations

	PM2,5	PM10
Building Density (r:150m)	-0,004	0,017
Street Connectivity (r:150m)	-0,009	-0,015
Figure-Ground (r:150m)	-,192*	-0,164
AOGR (r:150m)	-0,079	-0,106
APOGR (r:150m)	0,035	0,001
Park Ratio (r:150m)	,181*	0,169
Land-Use Mix (r:150m)	-,222*	-,203*
Low traffic volume (r:150m)	-,196*	-,201*
Medium traffic volume (r:150m)	-,216*	-,197*
High traffic volume (r:150m)	0,078	0,078
** p< 0.01 * p< 0.05		

When we look at the built environment variables remaining in the 150 m buffers, which are correlated with PM10 concentrations, we see that Land-Use Mix (*r*=-,203, p< 0.05), Low traffic (*r*=-,201, p< 0.05) and Medium Traffic Volume (*r*=-,197, p<

0.05) values is significantly correlated, and the correlation direction is negative. This means that as Land-Use Mix, Low and Medium Traffic Volume values increase, PM10 concentrations decrease. In general, Table 13 shows that there is a negative link between PM concentrations and all parameters except APOGR, Park Ratio, and High Traffic Volume. This shows that PM concentrations decrease as the values for APOGR, Park Ratio and High Traffic Volume decrease.

Finally, when the correlations of the urban built environment characteristics within the 200 m buffers with PM concentrations are examined (Table 14); It is seen that Figure-Ground (*r*=-,175, p< 0.05), Park Ratio (*r*=,180, p< 0.05), Land-Use Mix (*r*=-,293, p< 0.01), Low (*r*=-,180, p< 0.05) and Medium (*r*=-,230, p< 0.01) Traffic Volume values are correlated with PM2.5 concentrations. While the Park Ratio and PM2,5 concentration showed a positive correlation, other correlated built environment variables showed a negative correlation. When the urban environment variables that correlate with PM10 concentrations are examined, it is seen that AOGR (*r*=-,193, p< 0.05), Land-Use Mix (*r*=-,268, p< 0.01), Low (*r*=-,188, p< 0.05) and Medium (*r*=-,208, p< 0.05) traffic values are negatively correlated with PM10 concentrations. Here, unlike other buffer-sizes, we observe that the Active Green ratio also has a negative correlation with the PM10 concentration. This leads us to the conclusion that the rise in AOGR value in the 200 m buffers around each spot causes PM10 concentrations to decrease. In general, Table 13 shows that there is a negative link between PM2.5 concentrations and parameters other than building density, street connectivity, park ratio, and high traffic. This tells us that a decrease in building density, street connectivity, park ratio, and high traffic volume causes to a decrease in PM2.5 concentrations. For PM10 concentrations there is a positive link with building density, park ratio and high traffic volume. This means that a decrease in building density, park ratio, and high traffic volume causes to a decrease in PM2.5 concentrations.

Table 14. Correlation results of built environment features in 200m buffers and PM concentrations

	PM2,5	PM10
Building Density (r:200m)	0,022	0,052
Street Connectivity (r:200m)	0,002	-0,004
Figure-Ground (r:200m)	-,175*	-0,14
AOGR (r:200m)	-0,166	-,193*
APOGR (r:200m)	-0,038	-0,075
Park Ratio (r:200m)	,180*	0,164
Land-Use Mix (r:200m)	-,293**	-,268**
Low traffic volume (r:200m)	-,180*	-,188*
Medium traffic volume (r:200m)	-,230**	-,208*
High traffic volume (r:200m)	0,095	0,102
** p< 0.01 * p< 0.05		

1.a. Which features of the urban environment significantly affect outdoor air quality?

A single variable linear regression was used to compare the variables having significant correlations with PM concentrations. This method enabled the researcher to understand how many unit changes in PM concentrations could be explained with a one-unit change in each urban environmental variable. Performing this analysis the sub-question of the first question is answered.

First, linear regression was performed for the natural environment values correlated with PM10 values and for the built environment variables (of buffers having different radii) correlated with PM10 values, one by one (Table 15). The results of linear regression are as follows:

- As altitude goes up one value (in meters), PM10 goes down by 0,403 (µg/m³)

- As the temperature goes up one value (°C), PM10 goes down by 0,265 (µg/m³)
- As the relative humidity goes up one value, PM10 goes down by 0,229 (µg/m³)
- As the Figure-Ground values measured within 100m buffers go up one value, PM10 goes down by 0,228 (µg/m³)
- As the Medium traffic volume value measured within 100m buffers goes up one value, PM10 goes down by 0,188 (µg/m³)
- As the Land-Use Mix value measured within 150m buffers goes up one value, PM10 goes down by 0,191 (µg/m³)
- As the Low traffic value measured within 150m buffers goes up one value, PM10 goes down by 0,165 (µg/m³)
- As the Medium traffic value measured within 150m buffers goes up one value, PM10 goes down by 0,195 (µg/m³)
- As the AOGR value measured within 200m buffers goes up one value, PM10 goes down by 0,231 (µg/m³)
- As the Land-Use Mix value measured within 200m buffers goes up one value, PM10 goes down by 0,279 (µg/m³)
- As the Low traffic value measured within 200m buffers goes up one value, PM10 goes down by 0,145 (µg/m³)
- As the Medium traffic value measured within 200m buffers goes up one value, PM10 goes down by 0,205 (µg/m³)

According to the regression analysis results, the altitude has the most significant impact on PM10 concentrations from the natural environmental factors. Looking at the built environment properties in 100 m buffers, it is seen that Figure Ground has the highest effect on PM10. In 150 m buffers, it is seen that Medium Traffic Volume has the highest impact on PM10. In 200 m buffers, it is seen that Land-Use Mix has the highest effect on PM10 concentrations.

Table 15. Linear regression results of urban environment characteristics and PM10 concentrations

	Unstandardized coefficients		Standardized coefficients			OR (95%CI)	
Independent Variables	*B*	*SE*	Beta	*t*	*Sig.*	Lower	Upper
Altitude	-0,403**	0,068	-0,467	-5,925	<,001	-0,538	-0,268
Temperature	-0,265**	0,035	-0,559	-7,577	<,001	-0,334	-0,196
Relative Humidity	-0,229**	0,041	-0,448	-5,628	<,001	-0,309	-0,148
Figure-Ground (r:100m)	-0,228**	0,084	-0,235	-2,717	0,008	-0,393	-0,062
Medium traffic vol (r:100m)	-0,188*	0,089	-0,186	-2,123	0,036	-0,363	-0,013
Land-Use Mix (r:150m)	-0,191*	0,082	-0,203	-2,323	0,022	-0,354	-0,028
Low traffic vol (r:150m)	-0,165*	0,072	-0,201	-2,298	0,023	-0,308	-0,023
Medium traffic vol (r:150m)	-0,195*	0,087	-0,197	-2,257	0,026	-0,367	-0,024
AOGR (r:200m)	-0,231*	0,105	-0,193	-2,204	0,029	-0,438	-0,024
Land-Use Mix (r:200m)	-0,279**	0,089	-0,268	-3,123	0,002	-0,456	-0,102
Low traffic vol (r:200m)	-0,145*	0,068	-0,188	-2,147	0,034	-0,279	-0,011
Medium traffic vol (r:200m)	-0,205*	0,086	-0,208	-2,387	0,018	-0,376	-0,035
*p <.05, **p <.01							

Next, linear regression was performed for the natural environment values correlated with PM2,5 values and for the built environment variables (of buffers having different radius) correlated with PM2,5 values, one by one (Table 16). The results of linear regression are as follows;

- As altitude goes up one value (in meters), PM2,5 goes down by 0,401 (µg/m³)
- As the temperature goes up one value (ºC), PM2,5 goes down by 0,273 (µg/m³)

- As the relative humidity goes up one value, PM2,5 goes down by 0,239 (μg/m³)
- As the Figure-Ground values measured within 100m buffers go up one value, PM2,5 goes down by 0,239 (μg/m³)
- As the Medium traffic value measured within 100m buffers goes up one value, PM2,5 goes down by 0,19 (μg/m³)
- As the Figure-Ground values measured within 150m buffers go up one value, PM2,5 goes down by 0,177 (μg/m³)
- As the Park values measured within 150m buffers go up one value, PM2,5 goes up by 0,216 (μg/m³)
- As the Land-Use Mix value measured within 150m buffers goes up one value, PM2,5 goes down by 0,154 (μg/m³)
- As the Low traffic value measured within 150m buffers goes up one value, PM2,5 goes down by 0,154 (μg/m³)
- As the Medium traffic value measured within 150m buffers goes up one value, PM2,5 goes down by 0,204 (μg/m³)
- As the Figure-Ground values measured within 200m buffers go up one value, PM2,5 goes down by 0,153 (μg/m³)
- As the Park values measured within 200m buffers go up one value, PM2,5 goes up by 0,2 (μg/m³)
- As the Land-Use Mix value measured within 200m buffers goes up one value, PM2,5 goes down by 0,291 (μg/m³)
- As the Low traffic value measured within 200m buffers goes up one value, PM2,5 goes down by 0,132 (μg/m³)
- As the Medium traffic value measured within 200m buffers goes up one value, PM2,5 goes down by 0,216 (μg/m³)

According to the regression results, among all the natural environmental factors, the altitude has the most significant impact on PM2,5 concentrations. Looking at the built environment factors in 100 m buffers, it is seen that Figure Ground has the highest effect on PM2,5. In 150 m buffers, it is seen that Park Ratio has the highest impact on PM2,5. In 200 m buffers, it is seen that Land-Use Mix has the highest effect on PM2,5 concentrations.

Table 16. Linear regression results of urban environment characteristics and PM2.5 concentrations

	Unstandardized coefficients		Standardized coefficients			OR (95%CI)	
Independent Variables	*B*	*SE*	Beta	*t*	*Sig.*	Lower	Upper
Altitude	-0,401**	0,064	-0,488	-6,273	<,001	-0,528	-0,275
Temperature	-0,273**	0,032	-0,606	-8,545	<,001	-0,337	-0,21
Relative Humidity	-0,239**	0,038	-0,493	-6,357	<,001	-0,314	-0,165
Figure-Ground (r:100m)	-0,239**	0,079	-0,259	-3,013	0,003	-0,396	-0,082
Medium traffic vol (r:100m)	-0,19*	0,084	-0,198	-2,265	0,025	-0,357	-0,024
Figure-Ground (r:150m)	-0,177*	0,081	-0,192	-2,194	0,03	-0,337	-0,017
Park Ratio (r:150m)	0,216*	0,104	0,181	2,071	0,04	0,01	0,423
Land-Use Mix (r:150m)	-0,199*	0,078	-0,222	-2,552	0,012	-0,354	-0,045
Low traffic vol (r:150m)	-0,154*	0,069	-0,196	-2,248	0,026	-0,29	-0,018
Medium traffic vol (r:150m)	-0,204*	0,082	-0,216	-2,482	0,014	-0,366	-0,041
Figure-Ground (r:200m)	-0,153*	0,076	-0,175	-2,001	0,048	-0,304	-0,002
Park Ratio (r:200m)	0,2*	0,097	0,18	2,057	0,042	0,008	0,392
Land-Use Mix (r:200m)	-0,291**	0,084	-0,293	-3,441	<,001	-0,458	-0,124
Low traffic vol (r:200m)	-0,132	0,065	-0,18	-2,05	0,042	-0,26	-0,005
Medium traffic vol (r:200m)	-0,216**	0,081	-0,23	-2,654	0,009	-0,377	-0,055
*p <.05, **p <.01							

1.b. Do urban spots with less or more air pollution show a differentiation based on the urban environment characteristics of their surroundings?

To understand whether the urban spots with more or less air pollution differ according to their urban environmental characteristics, an *independent sample t-test* was applied between 20 urban spots with the highest and lowest PM10 and PM2.5 values. Eta square value is used to interpret the effect size of the urban environment characteristic. The formula for eta squared is as follows:

$\eta^2 = t2 / [t\ 2 + (N1 + N2 - 2)]$

An eta-squared value reflects the strength or magnitude related to a main or interaction effect. Eta-squared quantifies the percentage of variance in the dependent variable (Y) that is explained by the independent variables (X). The guidelines (proposed by Cohen, 1988) for interpreting this value are; 0.01=small effect, 0.06=moderate effect, and 0.14=large effect. Below, the author presents the findings regarding PM2.5 and PM10 values under different sub-headings.

Do urban spots with less or more PM2.5 values show a differentiation based on the urban environment characteristics of their surroundings?

First, an the independent sample t-test was conducted to compare the natural environment values for maximum and minimum PM2,5 concentrations (Table 17). In accordance with the significance value in Levene's test, the null hypothesis or alternative hypothesis is selected.

Looking at the Z values, there was a significant difference in Z values for min (*M*= 0.7, *SD*=0.1) and max (*M*= 0.4, *SD*=0.3) PM2,5 values (t (23.161) =4.244, p<0,01, two-tailed). The magnitude of differences in the means (*mean difference* = .323, *95% Cl*: .165 to .48) was quite large (η^2 =.322). For temperature, there was a significant difference in temperature values for min (*M*= 0.9, *SD*=0.3) and max (*M*= 0.01, *SD*=0.004) PM2,5 values (t (19.008) =12.936, p<0,01, two-tailed). The magnitude of differences in the means (*mean difference* = .883, *95% Cl*: .74 to 1.026) was quite large (η^2 =.815). For Relative Humidity, there was a significant difference in relative humidity values for min (*M*= 0.7, *SD*=0.2) and max (*M*= 0.05, *SD*=0.02) PM2,5 values (*t* (19.701) =13.661, *p*<0,01, two-tailed). The magnitude of differences in the means (*mean difference* = .667, *95% Cl*: .565 to .769) was quite large (η^2 =.831). For Wind Speed, there was no significant difference in wind speed values for min (*M*= 0.59, *SD*=0.16) and max (*M*= 0.5, *SD*=0.48) PM2,5 values (*t* (23.018) =.73, *p*= .473, two-tailed). The magnitude of differences in the means (*mean difference* = .084, *95% Cl*: -.153 to .321) was very small (η^2 =.014).

Table 17. t test results of PM2.5 concentrations and natural environment characteristics

						95% Confidence		
	t	df	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper	η^2
Altitude	4,244	23,161	<,001	0,323	0,076	0,165	0,480	0,322
Temperature	12,936	19,008	<,001	0,883	0,068	0,740	1,026	0,815
Relative Humidity	13,661	19,701	<,001	0,667	0,049	0,565	0,769	0,831
Wind Speed	0,730	23,018	0,473	0,084	0,115	-0,153	0,321	0,014

Table 17 shows that at 95% confidence interval, urban spots with less and more PM2.5 values show a statistically significantly difference based on altitude, temperature and relative humidity.

Second, the independent sample t-test was conducted to compare the built environment values in 100m buffers for maximum and minimum PM2,5 concentrations. Results show that at 95% confidence interval, urban spots with less and more PM2.5 values do not show a statistically significant difference based on any of the built environmental characteristics (e.g., figure-ground, building density, LUM, etc.) of their surroundings (r=100meters) (see Table 18).

Third, an independent sample t-test was conducted to compare the built environment values in 150m buffers for maximum and minimum PM2,5 concentrations. Looking at Table 19 results show that at 95% confidence interval, urban spots with less and more PM2.5 values show a statistically significant difference based on medium traffic volume (*t* (38) =2.263, $p<0,05$, two-tailed) (r=150meters). The magnitude of differences in the means was large (η^2 =.119). Other than that no significant difference was found.

Lastly, an independent sample t-test was conducted to compare the built environment values in 200m buffers for maximum and minimum PM2,5 concentrations. Results show that at 95% confidence interval, urban spots with less and more PM2.5 values show a statistically significant difference based on medium traffic volume (*t* (32.26) =2.445, $p<0,05$, two-tailed) (η^2 =.136) and park ratio (*t* (34.723) =-2.729, $p<0,05$, two-tailed) (η^2 =.164) (r=200meters) (see Table 20).

Table 18. t test results of PM2.5 concentrations and built environment characteristics within 100m buffers

						95% Confidence Interval of the Difference		
	t	df	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper	η^2
Building Density (r:100m)	1,335	32,391	0,191	0,069	0,051	-0,036	0,174	0,045
Street Connectivity (r:100m)	-1,570	38,000	0,125	-0,081	0,052	-0,186	0,024	0,061
Figure-Ground (r:100m)	1,781	38,000	0,083	0,106	0,060	-0,014	0,227	0,077
AOGR (r:100m)	1,369	38,000	0,179	0,077	0,056	-0,037	0,192	0,047
APOGR (r:100m)	-0,039	38,000	0,969	-0,002	0,057	-0,118	0,113	0,000
Park Ratio (r:100m)	-0,792	38,000	0,433	-0,040	0,051	-0,143	0,063	0,016
Land-Use Mix (r:100m)	0,883	38,000	0,383	0,057	0,064	-0,074	0,187	0,020
Low traffic volume (r:100m)	-0,683	30,237	0,500	-0,054	0,079	-0,216	0,108	0,012
Medium traffic vol. (r:100m)	1,542	38,000	0,131	0,105	0,068	-0,033	0,242	0,059
High traffic volume (r:100m)	-1,036	19,117	0,313	-0,052	0,050	-0,157	0,053	0,027

Table 19. t test results of PM2.5 concentrations and built environment characteristics within 150m buffers

						95% Confidence Interval of the Difference		
	t	df	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper	η^2
Building Density (r:150m)	1,077	38,000	0,288	0,053	0,049	-0,046	0,152	0,030
Street Connectivity (r:150m)	-0,741	38,000	0,463	-0,037	0,050	-0,138	0,064	0,014
Figure-Ground (r:150m)	1,635	38,000	0,110	0,093	0,057	-0,022	0,209	0,066
AOGR (r:150m)	1,361	38,000	0,182	0,063	0,046	-0,031	0,156	0,046
APOGR (r:150m)	-0,066	38,000	0,948	-0,004	0,055	-0,116	0,109	0,000
Park Ratio (r:150m)	-1,716	38,000	0,094	-0,075	0,044	-0,164	0,014	0,072
Land-Use Mix (r:150m)	1,570	38,000	0,125	0,090	0,058	-0,026	0,207	0,061
Low traffic volume (r:150m)	-0,112	38,000	0,912	-0,009	0,081	-0,172	0,154	0,000
Medium traffic volume (r:150m)	2,263	38,000	0,029	0,161	0,071	0,017	0,306	0,119
High traffic volume (r:150m)	-0,961	38,000	0,343	-0,049	0,051	-0,151	0,054	0,024

Table 20. t test results of PM2.5 concentrations and built environment characteristics within 200m buffers

						95% Confidence Interval of the Difference		
	t	df	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper	η^2
Building Density (r:200m)	1,108	38,000	0,275	0,054	0,049	-0,045	0,154	0,031
Street Connectivity (r:200m)	-0,710	38,000	0,482	-0,036	0,051	-0,139	0,067	0,013
Figure-Ground (r:200m)	1,550	38,000	0,129	0,086	0,055	-0,026	0,198	0,059
AOGR (r:200m)	1,770	32,145	0,086	0,074	0,042	-0,011	0,158	0,076
APOGR (r:200m)	0,422	38,000	0,675	0,022	0,053	-0,085	0,130	0,005
Park Ratio (r:200m)	-2,729	34,723	0,010	-0,110	0,040	-0,191	-0,028	0,164
Land-Use Mix (r:200m)	1,803	38,000	0,079	0,093	0,052	-0,011	0,198	0,079
Low traffic volume (r:200m)	0,011	33,910	0,992	0,001	0,089	-0,180	0,182	0,000
Medium traffic volume (r:200m)	2,445	32,260	0,020	0,175	0,071	0,029	0,320	0,136
High traffic volume (r:200m)	-1,511	20,312	0,146	-0,082	0,054	-0,195	0,031	0,057

Do urban spots with less or more PM10 values show a differentiation based on the urban environment characteristics of their surroundings?

As in the analysis for PM2.5 values, in the first step, the researcher compared the values for different natural environment features for the urban spots that received the highest and lowest PM10 concentration values (Table 21).

Looking at the Z values, there was a significant difference in Z values for min (*M*= 0.7, *SD*=0.1) and max (*M*= 0.3, *SD*=0.3) PM10 values (*t* (23.011) =4.666, *p*<0,01, two-tailed). The magnitude of differences in the means (*mean difference* = .354, *95% Cl*: .197 to .51) was quite large (η^2 =.364). For temperature, there was a significant difference in temperature values for min (*M*= 0.9, *SD*=0.3) and max (*M*= 0.01, *SD*=0.004) PM10 values (*t* (19.009) =12.943, *p*<0,01, two-tailed). The magnitude of differences in the means (*mean difference* = .883, *95% Cl*: .741 to 1.026) was quite large (η^2 =.815). For Relative Humidity, there was a significant difference in relative humidity values for min (*M*= 0.72, *SD*=0.22) and max (*M*= 0.05, *SD*=0.03) PM10 values (*t* (19.740) =13.725, *p*<0,01, two-tailed). The magnitude of differences in the means (*mean difference* = .67, *95% Cl*: .568 to .772) was quite large (η^2 =.832). For Wind Speed, there was no significant difference in wind speed values for min (*M*= 0.6, *SD*=0.16) and max (*M*= 0.6, *SD*=0.48) PM10 values (*t* (23.121) =.366, *p*= .718, two-tailed). The magnitude of differences in the means (*mean difference* = .042, *95% Cl*: -.195 to .278) was very small (η^2 =.004).

Table 21. t test results of PM10 concentrations and natural environment characteristics

						95% Confidence		
	t	df	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper	η²
Altitude	4,666	23,011	<,001	0,354	0,076	0,197	0,510	0,364
Temperature	12,943	19,009	<,001	0,883	0,068	0,741	1,026	0,815
Relative Humidity	13,725	19,740	<,001	0,670	0,049	0,568	0,772	0,832
Wind Speed	0,366	23,121	0,718	0,042	0,114	-0,195	0,278	0,004

Table 21 shows that at 95% confidence interval, urban spots with less and more PM10 values show a statistically significant difference based on altitude, temperature and relative humidity.

Second, the independent sample t-test was conducted to compare the built environment values in 100m buffers for maximum and minimum PM10 concentrations. Results show that at 95% confidence interval, urban spots with less and more PM10 values do not show a statistically significant difference based on any of the built environmental characteristics (e.g., figure-ground, building density, LUM, etc.) of their surroundings (r=100meters) (see Table 22).

Third, an independent sample t-test was conducted to compare the built environment values in 150m buffers for maximum and minimum PM10 concentrations. Looking at Table 23 results show that at 95% confidence interval, urban spots with less and more PM10 values show a statistically significant difference based on medium traffic volume (t (38) =2.19, p<0,05, two-tailed) (r=150meters). The magnitude of differences in the means was large (η^2 =.112). Other than that no significant difference was found.

Lastly, an independent sample t-test was conducted to compare the built environment values in 200m buffers for maximum and minimum PM10 concentrations. Results show that at 95% confidence interval, urban spots with less and more PM10 values do not show a statistically significant difference based on medium traffic volume(t (32.007) =2.473, p<0,05, two-tailed) (η^2 =.139) and park ratio (t (34.723) =-2.729, p<0,05, two-tailed) (η^2 =.164) (r=200meters) (see Table 24).

Table 22. t test results of PM10 concentrations and built environment characteristics within 100m buffers

						95% Confidence Interval of the Difference		
	t	df	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper	η^2
Building Density (r:100m)	1,204	32,090	0,237	0,062	0,051	-0,043	0,167	0,037
Street Connectivity (r:100m)	-1,476	38,000	0,148	-0,077	0,052	-0,182	0,028	0,054
Figure-Ground (r:100m)	1,892	38,000	0,066	0,109	0,058	-0,008	0,226	0,086
AOGR (r:100m)	1,306	38,000	0,199	0,074	0,056	-0,041	0,188	0,043
APOGR (r:100m)	-0,108	38,000	0,914	-0,006	0,057	-0,121	0,109	0,000
Park Ratio (r:100m)	-0,792	38,000	0,433	-0,040	0,051	-0,143	0,063	0,016
Land-Use Mix (r:100m)	0,973	38,000	0,337	0,062	0,064	-0,067	0,190	0,024
Low traffic volume (r:100m)	-0,494	30,182	0,625	-0,039	0,079	-0,201	0,123	0,006
Medium traffic volume (r:100m)	1,542	38,000	0,131	0,105	0,068	-0,033	0,242	0,059
High traffic volume (r:100m)	-1,036	19,117	0,313	-0,052	0,050	-0,157	0,053	0,027

Table 23. t test results of PM10 concentrations and built environment characteristics within 150m buffers

						95% Confidence Interval of the Difference		
	t	df	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper	η^2
Building Density (r:150m)	0,705	38,000	0,485	0,036	0,051	-0,067	0,140	0,013
Street Connectivity (r:150m)	-0,599	38,000	0,553	-0,029	0,049	-0,128	0,069	0,009
Figure-Ground (r:150m)	1,471	38,000	0,149	0,087	0,059	-0,033	0,207	0,054
AOGR (r:150m)	1,116	38,000	0,272	0,052	0,047	-0,042	0,146	0,032
APOGR (r:150m)	-0,311	38,000	0,757	-0,017	0,055	-0,130	0,095	0,003
Park Ratio (r:150m)	-1,716	38,000	0,094	-0,075	0,044	-0,164	0,014	0,072
Land-Use Mix (r:150m)	1,614	38,000	0,115	0,094	0,058	-0,024	0,211	0,064
Low traffic volume (r:150m)	0,105	32,555	0,917	0,008	0,080	-0,154	0,171	0,000
Medium traffic volume (r:150m)	2,190	38,000	0,035	0,157	0,072	0,012	0,301	0,112
High traffic volume (r:150m)	-1,096	19,197	0,287	-0,055	0,050	-0,160	0,050	0,031

Table 24. t test results of PM10 concentrations and built environment characteristics within 200m buffers

						95% Confidence Interval of the Difference		
	t	df	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper	η^2
Building Density (r:200m)	0,665	38,000	0,510	0,033	0,050	-0,068	0,135	0,012
Street Connectivity (r:200m)	-0,399	38,000	0,692	-0,019	0,049	-0,118	0,079	0,004
Figure-Ground (r:200m)	1,364	38,000	0,181	0,077	0,057	-0,037	0,191	0,047
AOGR (r:200m)	1,510	30,410	0,141	0,062	0,041	-0,022	0,147	0,057
APOGR (r:200m)	0,175	32,968	0,862	0,009	0,052	-0,097	0,115	0,001
Park Ratio (r:200m)	-2,729	34,723	0,010	-0,110	0,040	-0,191	-0,028	0,164
Land-Use Mix (r:200m)	1,847	38,000	0,073	0,096	0,052	-0,009	0,202	0,082
Low traffic volume (r:200m)	0,211	33,324	0,834	0,019	0,088	-0,160	0,197	0,001
Medium traffic volume (r:200m)	2,473	32,007	0,019	0,175	0,071	0,031	0,319	0,139
High traffic volume (r:200m)	-1,433	19,130	0,168	-0,074	0,052	-0,183	0,034	0,051

Along with point-based comparisons, region-based comparisons of the urban environment and outdoor air quality data were made. All of the values obtained for the region can be seen in Table 25. Results show that:

- There is a contradiction in terms of altitude. It is observed that the highest PM concentrations were measured in the Sincan region (*PM10* = 145.82, *PM2,5* = 147.45, *Sl* = 824.98), which has the lowest altitude. However, the PM concentrations are also quite high in the Mamak region (*PM10* = 126.09, *PM2,5* = 133.408, *Sl* = 952,81), which has the highest altitude. Contrary to the findings presented before, when the mean values of the regions were compared, it is seen that there is no relationship between altitude and PM concentrations.
- When the temperature values are analyzed, it is observed that the PM concentrations obtained in the mobile measurement results decrease as the temperature values increase. In other words, it can be seen that there is a negative correlation between Mobile PM measurements and temperature values at the regional scale.
- There is a negative correlation between the relative humidity values and the 24-hour PM2.5 observations. It has been found that as humidity rises, PM2,5 concentrations fall.
- There is no correlation between the wind speed values and PM concentrations. The Sincan region, where the wind speed is the highest, has the highest PM values, while the Mamak region, where the wind speed is the lowest, has the second-highest PM values.
- In terms of Figure-Ground and Building Density values, it is seen that the highest values are seen in Mamak and Çankaya Central Region, but the region with the highest concentrations of pollutants is the Sincan region. Therefore, when analyzed on a regional basis, it is seen that there is no correlation between the values.

- In terms of Land-Use Mix, it is observed that there is a negative correlation with the mobile measurements, and PM concentrations decrease as the Land-Use Mix ratio increases.

- Considering the AOGR rates, it is seen that the lowest active green area and the highest PM concentrations are in the Sincan Region, the highest active green area and the lowest PM concentrations are in the Çankaya Central Region. However, although the active green area in the Mamak Region is higher than in the Çankaya Periphery, we see that the PM concentrations here are higher than in the Çankaya Periphery. This situation can be explained by the fact that unstructured lands covering large areas in Çankaya Periphery are considered as passive green areas, as we can see in Figure 29. Therefore, it can be said that there is a negative correlation between AOGR and mobile PM measurements on a regional basis.

- There is no relationship between APOGR and Park Ratio and PM concentrations.

- If the Sincan region is excluded from correlation while looking at Street Connectivity, it is noted that there is a positive correlation between mobile measurements and the other 3 regions. It is seen that mobile PM measurements decrease as connectivity decreases. The Sincan region breaks the correlation since, despite having the lowest connectivity rates, it also has the highest PM concentrations.

- When looking at low traffic volume values from a regional perspective, it is seen that they show a negative relationship with PM concentrations. While the highest low traffic volume values are observed in Çankaya Central and Peripheral Regions, the lowest PM concentrations are observed in these regions. It is seen that the highest PM values are in Mamak and Sincan Regions, which have the lowest low traffic volume values.

- When we look at the medium traffic values, it is observed that there is no relationship on a regional basis. While the highest medium traffic volume values are observed in Mamak and Çankaya Center regions, it is seen that the PM concentrations in these two regions are the lowest. It is seen that the lowest medium traffic volume value is in the Sincan region, while the highest PM values are also in this region. However, when the Mamak region is ignored, it can be said that there is a negative correlation between mobile measurements and medium traffic volume values.
- It is seen that high traffic volume values correlate positively with the 24-hour measurements on a regional basis in all regions except Sincan Region. The Mamak region has the highest high traffic volume value and the highest concentrations of PM2.5, whereas the Çankaya Periphery region has the lowest high traffic volume value and lowest concentrations of PM2.5.
- When the distance to the nearest industrial areas is examined, it is seen that Sincan is between 2 industrial zones and is very close to these industrial areas. As expected, the highest PM concentration values are observed in this region. It is seen that the most distant region to the industrial areas is Çankaya Central region and the lowest PM concentrations obtained in mobile measurements are in this region. There is a significant statistical difference in terms of PM values in Sincan and Çankaya Merkez. However, the values detected in Mamak and Çankaya Periphery regions don't show any correlation.

When the regions are evaluated as central and peripheral regions, it is seen that Çankaya Central region has less PM concentration than Sincan and Çankaya Peripheral regions, based on mobile measurements. Considering the 24-hour measurements, it is seen that the air quality in the Çankaya Periphery region is better than in other regions. Although the Sincan region is located on the periphery of the Ankara Metropolitan city, it is seen that it does not show a periphery feature in terms of urban form characteristics other than having lower building areas than central region as we can see from urban form analyses (see Figures 26,27,28,29. The highest pollutant concentrations are taken in the Sincan region both in mobile measurements and in 24-hour measurements. The high PM concentrations in Sincan can be attributed to the fact that there are two industrial areas located very close to this region. The selected central and peripheral neighborhoods generally are incompatible within, in terms of air quality.

Table 25. Values for the urban environment characteristics and outdoor air quality at the regional scale

	Sincan	Mamak	Çankaya Periphery	Çankaya Center
Altitude	824,98	952,81	904,17	924,91
Temperature	12,30	12,63	16,60	17,47
Relative Humidity	43,83	44,47	58,00	55,23
Wind Speed	1,90	0,97	1,57	1,53
Figure-Ground	0,24	0,43	0,12	0,40
Building Density	0,97	1,24	0,47	1,13
Land-Use Mix	0,48	0,47	0,54	0,59
AOGR	0,39	0,45	0,43	0,50
APOGR	0,53	0,46	0,68	0,50
Park Ratio	0,06	0,05	0,13	0,02
Street Connect.	98,19	115,28	100,18	93,10
Low traffic	2092,73	1741,27	3321,76	3587,65
Medium traffic	118,03	1779,75	512,76	2045,71
High traffic	0,00	277,00	4,46	42,30
Proximity to nearest industry (km)	4,75	9,11	8,45	11,05
Proximity to 2nd nearest industry (km)	4,82	13,68	11,26	12,57
PM10_µg/m³	145,82	126,09	116,48	75,69
PM2,5_µg/m³	147,45	133,08	117,09	73,43
PM2,5_µg/m³ - 24h	127,72	114,72	26,70	48,56

4.2 Understanding the Relationship between Outdoor Air Quality and Childhood Asthma

The second major question of the thesis questioned whether there a relationship between urban environment-caused outdoor air pollution and childhood asthma. The author asked one sub-research question to respond this major question, which can be seen below.

2. Is there a relationship between urban environment-caused outdoor air pollution and childhood asthma

2.a. Are children diagnosed with asthma living in environments with more intense air pollution?

The link between outdoor air quality and childhood asthma is examined on regional basis. Results show that the variation in PM concentrations does not appear to explain the variation in the rate of childhood asthma. While the highest childhood asthma rate (*CAR*) is observed in the Mamak region (*CAR*=5), it is seen that this region lags behind the Sincan region in terms of PM concentrations (Table 26). Since a relatively high CAR is also seen in the Sincan region (*CAR*=4.1), this situation can be explained to some extent. When the Çankaya Periphery Region values are examined, it is seen that the lowest childhood asthma rate (*CAR*=3.6) is in this region. In contrast, the PM concentration values obtained in mobile air quality measurements are higher in this region (117.1 $\mu g/m^3$) than in the Çankaya Center region (73.4 $\mu g/m^3$). However, this situation can be explained by the measurements taken 24 hours since the lowest PM2.5 concentration (48.6 $\mu g/m^3$) is seen in the Çankaya Periphery region. When the Sincan region is ignored, it can be said that 24-hour PM2.5 measurements and childhood asthma rates are positively correlated.

Regardless of the total number of children registered, when we look at the numbers of physician-diagnosed children in the regions, the numbers are positively correlated with the mobile PM measurements. As can be seen from Table 26, the most physician-diagnosed children are in Sincan Region, where the PM concentrations are highest, and the least physician-diagnosed asthma cases are in Çankaya Center Region, where the PM concentrations are lowest. One should be careful in interpreting these findings since more children are registered to a public health center in Sincan than in Çankaya Center region.

When the asthma values as periphery and central regions are examined, results show that the rates of asthma are lower in the peripheral regions than in the central regions. The periphery and center, however, do not exhibit any correlation when we base our analysis on the total number of registered child patients.

Table 26. Regional values of air quality and childhood asthma data

	Air Quality Data			Health Data	
	Mobile Measurements		24h Measurements		
	PM10_µg/m³	PM2,5_µg/m³	PM2,5_µg/m³	Childhood asthma rates (physician diagnosed children / total number of children)	7_12 aged physician diagnosed children
Sincan	145,82	147,45	127,72	4,11	975
Mamak	126,09	133,08	114,72	4,96	835
Çankaya Periphery	116,48	117,09	26,70	3,62	185
Çankaya Center	75,69	73,43	48,56	4,93	159

4.3 Understanding the Relationship between Urban Environment Characteristics and Childhood Asthma

The thesis asked one main and one sub-research question to investigate the relationship between urban environment characteristics and childhood asthma. This questions can be seen below.

3. What are the physical characteristics of the neighborhoods where children are more prone to asthma?

3.a. Which urban environment characteristics at the neighborhood scale play a role in promoting childhood asthma?

Table 27 illustrates the findings from a comparison of each urban environmental characteristic with childhood asthma rates and the number of physician-diagnosed children. The results are as follows:

- There is no correlation between the altitude and the rate of childhood asthma. However, when the Sincan region is omitted, there is a positive correlation. Mamak has the highest altitude and the highest rate of asthma, while the Çankaya Periphery region has the lowest altitude and asthma rate. It is observed that there is no correlation between the numbers when we consider the number of children with asthma and altitude values.
- In terms of temperature, it is seen that there is a negative correlation between the temperature values of the regions and the number of children with asthma in the regions. It is seen that the number of patients decreases as the temperature values in the region increase. It is observed that there is no relationship between asthma rate and temperature values.
- It is seen that there is no relationship between the relative humidity and the number of children with asthma or asthma rates. Also, there is no relation between the wind speed values and the number of children with asthma or asthma rates.

- There is a positive correlation when Figure-Ground and asthma rates are investigated. As the figure-ground value increases, the rate of asthma also increases. There is no significant relationship between the values when the number of patients and Figure-Ground values are compared ($p>0.05$).
- Building density values were shown to be positively related with asthma rates but not with the number of children who had the illness.
- When the Mamak region is not taken into account, there is a negative correlation between the number of children with asthma diagnosis and the Land-Use mix. Although the lowest land-use mix ratio is in Sincan, the number of children with asthma is highest in this region. Simarly, although the highest rate of land-use mix is in the Çankaya Center region, the number of children with asthma is the lowest here. There is no correlation between land-use mix and the prevalence rate of asthma.
- There is a negative correlation between AOGR values and the number of children with asthma when we exclude one of the Mamak or Çankaya Peripheral regions from the correlation. It is seen that the number of children with asthma decreases as the AOGR rate increases in the regions. There is no relationship between asthma prevalence rates and AOGR.
- There appears to be a negative correlation between APOGR and the prevalence of asthma. The highest APOGR and lowest asthma prevalence were seen in Çankaya Periphery, while it is seen that the lowest APOGR rate and the highest asthma prevalence are in the Mamak region. It is seen that there is no relationship between the number of children diagnosed with asthma and APOGR.
- Park Ratio values do not appear to correlate with asthma rates or the number of children with asthma.
- In terms of street connectivity, excluding the Sincan region, there is a positive correlation between Street connectivity values and the number of children

with asthma. The lowest street connectivity rate and the lowest number of children with asthma are seen in the Çankaya Center region, while the highest street connectivity rate and the highest number of children with asthma are seen in the Mamak region.

- Low and medium traffic volume values do not show a correlation either with the prevalence of asthma or with the number of children diagnosed with asthma.
- There is a positive correlation between asthma prevalence and high traffic volume values when the Sincan region is excluded from the correlation. Regarding the number of kids with asthma, there is no relationship.
- When either Mamak or Çankaya Peripheral regions are ignored from the analysis, it is seen that there is a negative correlation between the distance to industrial areas and the number of children with asthma. The region closest to the industry and having the highest number of asthmatic children is the Sincan region, while the region farthest from the industry and having the lowest number of children with asthma is Çankaya Center.

Table 27. Regional values of urban environment and childhood asthma data

	Sincan	Mamak	Çankaya Periphery	Çankaya Center
Altitude	824,98	952,81	904,17	924,91
Temperature	12,30	12,63	16,60	17,47
Relative Humidity	43,83	44,47	58,00	55,23
Wind Speed	1,90	0,97	1,57	1,53
Figure-Ground	0,24	0,43	0,12	0,40
Building Density	0,97	1,24	0,47	1,13
Land-Use Mix	0,48	0,47	0,54	0,59
AOGR	0,39	0,45	0,43	0,50
APOGR	0,53	0,46	0,68	0,50
Park Ratio	0,06	0,05	0,13	0,02
Street Connectivity	98,19	115,28	100,18	93,10
Low traffic volume	2092,73	1741,27	3321,76	3587,65
Medium traffic volume	118,03	1779,75	512,76	2045,71
High traffic volume	0,00	277,00	4,46	42,30
Proximity to nearest industry (km)	4,75	9,11	8,45	11,05
Proximity to 2nd nearest industry (km)	4,82	13,68	11,26	12,57
Childhood Asthma Rate	4,11	4,96	3,62	4,93
7_12 aged physician diagnosed children	975	835	185	159

CHAPTER 5

DISCUSSION

This chapter discusses to what extent the research results obtained from this thesis are in line or contrary to the findings in the existing literature. This chapter is organized under three sub-headings in accordance with the main headings of the results section. It starts with a discussion of the results regarding the relationship between the urban environment and outdoor air quality. Next, it discusses the results regarding the link between outdoor air quality and childhood asthma. Finally, it discusses the results regarding the relationship between the urban environment and childhood asthma. This chapter also highlights the contribution of this thesis to the existing knowledge and questions the validity of the findings with regard to the research design, data collection and data analysis.

5.1 A Discussion of the Findings Regarding the Relationship between Urban Environment and Outdoor Air Quality

As stated in Chapter 2, few studies have monitored air pollution at the street-level and linked the findings from these assessments to different urban environmental characteristics. The majority of the literature compares the air quality levels of cities by using data obtained their air quality monitoring stations, and approach the urban environment characteristics of these settlements from a macro-scale perspective. Studies that use street-level measurements examine the impact of several urban environment characteristics, such as traffic (Zwack et al., 2011), land-use and building density (M. Liu et al., 2021) and urban parks (Qu et al., 2019), on outdoor air quality. No study has every approached the topic by focusing on the impacts of various urban environmental characteristics.

Before initiating the research, the author formulated a number of assumptions for each of the research questions posed in this thesis. These assumptions were noted in Chapter 1. In the paragraphs below, the author discusses each finding of the thesis with regard to the related assumption and the knowledge in the existing literature.

First, the researcher's assumption regarding the altitude was that air pollution would decrease as the altitude increased. This thesis found a negative correlation between altitude and outdoor air quality (*r=-,488 for PM2.5; r=-,467 for PM10*), which supports the researcher's initial assumption. In other words, this finding supports the results in the existing literature (see, e.g., Ning et al., 2018; Warlina et al., 2019).

Second, the researcher's assumption regarding meteorological values was that air pollution is less in areas with low temperatures, high relative humidity and high wind speed. This research revealed a negative correlation between the temperature (*r=-,606 for PM2.5; r=-,559 for PM10*), relative humidity (*r=-,493 for PM2.5; r=-,448 for PM10*) and PM concentrations, indicating that the PM concentrations decreased as the temperature and relative humidity increased. However, no significant relationship was found between wind speed values and PM concentrations ($p>0.05$). The findings of the thesis only supported the researcher's assumptions about relative humidity. The findings of this thesis are contrary to what scholars like S. Kim et al. (2015), Leung & Gustafson Jr. (2005), Roberts (2004) and Jayamurugan et al. (2013) found in their studies which used station data. There is also a study in literature conducted on a street scale that did not find any correlation between PM concentrations and temperature (Edussuriya et al., 2014). However, in a study published in 2022 (Wu et al., 2022), the same conclusion was reached as the same result reached within the scope of this thesis. In their study based on the city of Beijing, Wu et al. (2022) found that PM concentrations increase as temperature decreases. So, consistent with the findings in this study, a negative correlation was found between temperature and PM concentrations.

Third, the researcher's assumption regarding figure-ground analysis was that higher void spaces mean higher air quality. However, a negative correlation was found between solid/void ratios and PM concentrations in 100 (*r=-,259 for PM2.5; r=-,235 for PM10*), 150 (*r=-,192 for PM2.5*), and 200 m (*r=-,175 for PM2.5*) buffers placed around 128 points where air quality measurements were taken. No study in the literature has ever compared the solid/void ratio and air pollution at the street scale. The author explains this unexpected finding with her research design. Because air quality is an outcome of multiple factors, and since the author did not control for other built environmental variables that may affect the PM concentrations (e.g., buffers that have low greenness index and high solid/void ratios versus high greenness index and high solid/void ratios) in her research design, one should be careful with interpreting the findings of this research. The author, once again, notes that to the best of researcher’s knowledge this is the first study that aimed at linking childhood asthma to outdoor air quality and urban environmental characteristics (or vice versa). Future research may increase the validity of the findings presented here, not only by changing the data collection techniques (like for example using passive sampling for monitoring street-level air quality), but also by, for example, controlling the variables during data analysis.

Fourth, the researcher's assumption regarding building density was that air pollution would increase as the building density increases. As mentioned in Chapter 2, there are findings in the literature regarding the effects of building density on outdoor air quality (Liang et al., 2021; J. Yang et al., 2020). Also, there is a study using different buffer sizes and measuring the street-level impact of building density on air pollution (M. Liu et al., 2021). Using the data modeled, Liu et al. (2021) determined that an increase in the building density in a 200 m buffer would have a negative effect on PM 2.5 concentrations. However, no correlation was found between building density and PM concentrations in any buffer size within the scope of this thesis. Again, one possible reasons of this unexpected finding may the way the research was designed in this thesis. Another possible explanation could be that, perhaps factors like the materials of the buildings (e.g., materials that absorb or release heat) can be more important in affecting outdoor air quality than the building density.

Fifth, the researcher did not make any assumptions about land-use mix and air quality because there is a literary disagreement on this topic. Some research findings support that places with high land use diversity (which are often compact in form) are the places that have less air pollution (Bechle et al., 2015; McCarty & Kaza, 2015), and some research findings support that places with high land use diversity have more building surfaces, resulting in increased heat absorption which causes more air pollution (Stone & Rodgers, 2001; Y. Zhang & Gu, 2013). The results of this thesis are consistent with previous research, which demonstrated that high land use diversity improves air quality. Specifically, land-use mix ratios in 150 (*r=-,222 for PM2.5; r=-,203 for PM10*), and 200 m (*r=-,293 for PM2.5; r=-,268 for PM10*), buffers were found to be negatively correlated with both PM10 and PM2.5 concentrations.

The researcher's assumption regarding open and green areas was that air pollution decreases as open and green areas increase. Although the formulas used within this research weren't used in any research before, studies using NDVI prove that as the green index increases, air pollution decreases (Gajjar et al., 2021; Zhan et al., 2018). Also, Qu et al. (2019) found that Urban Parks have an important effect on PM concentrations. There are different rates in terms of open and green areas calculated (AOGR, APOGR, PR) within the scope of this thesis, as was mentioned in the methodology chapter. Consistent with the literature, in 200m buffers, a negative correlation has been found between PM10 and active open green ratio (*r=-,193*). However, it has been found that there is a positive correlation between PM2.5 concentrations in 150 (*r=,181*) and 200 m (*r=,180*) buffers and Park Ratio. This issue can be explained by the fact that the parks considered within the scope of the study are mostly neighborhood parks, some of which may not have an earthen surface, and that there are no large-scale urban parks present in the studied locations.

The researcher's assumption on being near industrial areas was that they have detrimental effects on air quality. The literature has proven that industry causes air pollution, and this air pollution has adverse effects on human health (Morin et al., 2012; Pope, 1989). Within the scope of this thesis, region-based comparisons were made regarding industrial areas. No correlation was found between the proximity to industrial areas and air quality; however, high concentrations measured in Sincan can be attributed to industrial areas since the region is very close to two different industrial areas. Related to the latter note, it should also be emphasized that none of the selected regions housed heavy industrial areas, which might have also affected the results presented in this thesis regarding the role of proximity to industrial areas in outdoor air quality.

The researcher did not make any assumptions regarding how street connectivity would affect air quality because of the contradictory results in the literature. No correlation was found between street connectivity and PM concentrations within the purview of this thesis. This can be explained again with the research design. No variables have been controlled during data analysis. In further studies, analysis can be performed by controlling some variables.

The researcher’s assumption of high traffic volume and air pollution was that they would be positively correlated. Many studies found that traffic is one of the critical factors that cause air pollution (Dastoorpoor et al., 2016; Lockhart et al., 2015; Soegoto et al., 2019). However, no correlation was found between high traffic volume and PM concentrations. In all three buffer sizes, a negative correlation was found between medium traffic and PM concentrations, whereas in 150 and 200 m buffers, a negative correlation was found between low traffic and PM concentrations. This can be explained by the fact that although there is no road having high traffic volume in the Sincan region, the region is the most polluted area. In her further studies, the researcher will repeat the analysis by comparing other regions except the points in the sincan region. Further studies of the researcher will provide a better explanation of this result.

All in all, as a result of point-based evaluations, findings either confirmed or refuted the researcher's assumptions. Considering the urban environment and air quality data on a regional basis;

- Similar to the findings in the study of Wu et al. (2022), a negative correlation was found between temperature and PM concentrations.
- A negative correlation was found between land-use mix and PM concentrations, similar to the findings in the study of Bechle et al. (2015).
- Finally, a negative correlation was found between AOGR and PM concentrations, similar to the findings in the literature.

As a final point, the author once again acknowledges that the research design, data collection and analysis techniques chosen in this resarch might have affected the validity of the findings. For example, there are various techniques for measuring street connectivity; this thesis used one of these techniques. Similarly, greenness of an area can be measured in many different ways; there might be more accurate ways to measure the greenness of areas at the street-level, but utilizing these techniques demand time and financial capital. In addition, if the neighborhoods selected from the central and peripheral regions were different, the results would certainly have changed, especially the Sincan region. The industrial areas around the Sincan region were known and included in the study in order to examine the effect of the industrial areas on the air quality. However, the results of the study would have been different if a region bordering large green areas had been chosen in the southeast region of Ankara instead of Sincan. At the same time, the fact that the PM measurements were taken from the roads (even if a child size was taken into account) is likely to affect the results. When measuring on the streets, the measurements were affected by the exhaust of the vehicles in front. Taking measurements from sidewalks, parking lots and schoolyards rather than streets would have given more accurate results. However, in this study, which was conducted in 4 different regions with large areas, this was not possible due to both technical and financial reasons.

5.2 A Discussion of the Findings Regarding the Relationship between Outdoor Air Quality and Childhood Asthma

There is numerous research in the literature on the negative effects of outdoor air pollution on childhood asthma (Hadley et al., 2018b; Pénard-Morand et al., 2010; Zora et al., 2013). The researcher's assumption on this issue was: "Outdoor air pollution caused by the urban environment worsens childhood asthma." However, no relationship was found between asthma prevalence and outdoor air quality within the scope of this thesis. When the researcher examined the literature, she discovered that comparisons were frequently based on patient numbers, particularly in studies that use hospital data (Iskandar et al., 2012; Sunyer et al., 1997). When the comparison is made based on the number of patients, a positive correlation was found between the PM concentrations taken in mobile measurements and the number of physician-diagnosed asthma patients, which supports the literature.

The fact that health data is a general rather than a point data within the scope of the study should not be disregarded. Although it was the researcher's intention to use questionnaires from parents of students will be collected within the TÜBİTAK project, the researcher had to use secondary data due to Covid-19. The use of questionairre data will surely give more accurate results.

5.3 A Discussion of the Findings Regarding the Relationship between Urban Environment and Childhood Asthma

Few studies investigated the link between urban environment characteristics and childhood asthma(Corburn et al., 2006). No study has ever considered the role of a wide range of urban environment characteristics on childhood asthma as this thesis did.

The researcher's assumption about this last relationship was: "Urban environment characteristics which cause bad air quality have an effect on childhood asthma. The researcher assumes that urban environmental features, which she hypothesized to cause air pollution, also trigger asthma.” In light of this assumption, the effects of all urban environmental characteristics in this thesis on childhood asthma are discussed.

Regarding altitude, a positive correlation can be detected between asthma prevalence and altitude when Sincan is ignored. The fact that the neighborhood units in Sincan disrupt this correlation can be explained by the fact that they are very close to the industrial areas. However, point-based analyses reveal a negative correlation between altitude and air quality. This finding contradicts the researcher’s assumption.

In terms of meteorological values, it is discovered that there is a negative correlation between the number of patients and temperature and no relation with relative humidity and wind speed. The association between temperature levels and pediatric asthma has been the subject of numerous studies in the literature. While some of the studies found a positive correlation between temperature and childhood asthma (Hashimoto et al., 2004; Winquist et al., 2016), some found a negative correlation (Guo et al., 2012; Xirasagar et al., 2006), and some did not detect any significant relationship (Abe et al., 2009). Therefore, the results of this thesis support the literature that found a negative correlation between temperature and childhood asthma. Lastly, while the temperature finding supports the researcher's assumption, the absence of a relationship between relative humidity and childhood asthma contradicts the researcher's assumption. Because it has been determined that there is a negative correlation between relative humidity and PM concentrations

Contrary to the result in point-based air quality and urban environment analysis, a positive correlation was found between Figure-Ground and asthma prevalence.

It was also found that there was a positive correlation between building density and asthma prevalence. However, the association between building density and air pollution was not found to be significant in point-based comparisons. This contradicts the researcher's assumption.

It was discovered that the Mamak region prevented a significant correlation when the land-use mix was evaluated. It was found that there was a negative correlation between the land-use mix and the number of asthma patients when the Mamak region was excluded. Based on this finding, the hypothesis of the researcher is supported.

The parking ratio, one of the active open and green space ratios, was not correlated with childhood asthma, in contrast to its correlation with air quality. A negative relationship between AOGR and the number of asthmatic patients can be found when one of the Çankaya Periphery or Mamak regions is ignored. This supports the assumption of the researcher. APOGR and the prevalence of asthma were found to be negatively correlated. This, however, defies the researcher's assumption because there was no association between air pollution and APOGR.

When any of the Mamak or Çankaya Peripheral regions were excluded from the correlation, it was seen that the proximity to the industrial areas was negatively related to both air pollution and the number of children with asthma.

When we did not include the Sincan region in the correlation, both region-based pollution and the number of children with asthma were positively correlated with street connectivity.

When examined in terms of high traffic, it is seen that both air pollution and asthma prevalence have a positive relationship if the Sincan region is excluded from the correlation. This supports the assumption of the researcher.

As stated in before, few studies have compared childhood asthma and different urban environment characteristics at this scale. In this respect, this thesis has made a great contribution to the literature. However, as mentioned in the previous section, more detailed asthma data could have changed the relevant results. Address-based acquisition of doctor-diagnosed patient data or conducting a survey in the researched neighborhood units will give much more accurate results.

CHAPTER 6

CONCLUSION

The rise in urban air pollution is a matter of worldwide concern. The intense air pollution in the urban environments affects our health negatively. Children are most affected group due to their fast metabolism. Their bodies are developing rapidly and breath faster than adults. One of the illnesses caused by or worsened by exposure to outdoor air pollutants is asthma, which, if turns into a chronic condition in childhood, negatively impacts the ones' quality of life in the rest of his/her life. Asthma prevalence has significantly increased worldwide during the past few decades, especially in children. The dynamics of this occurrence suggest that it is caused by environmental changes rather than by the influence of personal factors like age, gender and heredity. This research was designed to investigate the relationship between the urban environment, outdoor air quality and childhood asthma. To this end, three major research questions were asked.

The results of the study show that there is a negative relationship between natural environment variables (such as altitude, temperature and relative humidity) and PM concentrations. Built environment seems to affect outdoor air quality either positively or negatively. The results of this relationship depend on the methods used. When investigated inside 100m buffer zones, figure-ground ratios of settlements and medium traffic volume rates inside the neighborhoods have a negative relationship with PM2.5 and PM10 concentrations. When investigated inside 150m buffer zones, land-use mix and both low and medium traffic volume rates have a negative relationship with PM2.5 and PM10 concentrations; figure-ground ratio has a negative and park ratio has a positive relationship only with PM2.5 concentrations. Finally, when investigated inside 200m buffer zones, land-use mix and both low and medium traffic volume ratios have a negative relationship with PM2.5 and PM10 concentrations; figure-ground ratio has a negative and park ratio has a positive relationship with PM2.5 concentrations; active open green space ratio (AOGR) has a negative relationship only with PM10 concentrations.

This study found that there is a positive correlation between the number of children (aged 7-12 years) with doctor-diagnosed asthma and outdoor air pollution. Evaluating the general findings of the last research question, which questioned the relationship between urban environment and childhood asthma: considering asthma prevalence, a negative correlation was found between APOGR and high traffic values, and a positive correlation was found between altitude, figure-ground and Building density; considering the number of children diagnosed with asthma aged 7-12, a negative correlation was found between temperature, land-use mix, AOGR, proximity to nearest industry, and a positive correlation was found between street connectivity.

The second chapter of this thesis, a review of the findings in the existing literature, may explain some of the relationships presented here. It was emphasized that there are components that can cause air pollution in urban environments and that air pollution caused by these components can cause or trigger childhood asthma. When the results are taken into account in this context, it becomes clear that temperature, land-use mix, AOGR, high traffic volumes and distance to the nearest industrial areas are the urban environment components that have correlation at the same direction with PM concentrations, and the number of children with asthma between the ages of 7-12. Some urban environment characteristics were discovered to be correlated with childhood asthma but not correlated with PM concentrations (e.g., APOGR, building density) or correlated in different directions with PM concentrations and childhood asthma (e.g., figure-ground, altitude). This situation necessitates measuring air quality in studies focusing on the relationship between childhood asthma and urban environment characteristics. The findings obtained in this thesis showed that without air quality data, it would be wrong to establish the link between the urban environment and childhood asthma.

6.1 Implications for City Planning

This thesis is intended to guide city planners and designers regarding problematic areas and how these areas can be improved in the context of decreasing air pollution and asthma rates in children. It also aims to provide guidance regarding the types of planning and design practices that should be used to improve the outdoor air quality in newly constructed settlements. In line with these aims, analyses conducted within the purview of the thesis have revealed which urban environmental factors have an impact on outdoor air quality. These analyses were conducted at the point and regional levels. Also, it was discovered which elements of the urban environment were linked to childhood asthma.

As shown in this thesis the cities' physical environmental characteristics significantly impact how concentrated or diffused the pollutants are at the street level. Urban planning could substantially contribute to the dispersion of street-level air pollution, especially if it is combined with other disciplines. In addressing these problems, work that transcends disciplinary boundaries, bringing medical doctors, public health specialists, urban planners, environmental engineers, and geographers, will be critical.

Based on the findings of the thesis about the urban environment and outdoor air quality, the author once again highlights that the natural environment characteristics of the urban environment affect outdoor air quality. That's why city planners should give more attention to altitude and air flow conditions while proposing any kind of new land-uses. From built environment characteristics, figure-ground and land-use mix ratios were negatively correlated with the PM concentrations, indicating that compact urban forms are better in terms of air quality.

Compact urban form is defined as areas with high density and mixed land-use (Burton et al., 2003). There are two opposing views on urban areas: the views of the centrists and decentrists. Centrists are in favor of 'Compact Urban Forms' (Newman & Kenworthy, 1989), whereas decentrists are in favor of 'Market Solutions' in urban areas (Gordon & Richardson, 1989). Desentrists claims that compact cities do not reflect the hard reality of economic demands. According to them the problem with the compact city is that it ignores the causes and effects of decentralisation, and the benefits that it might bring (Thomas &Cousins, 2003). Centrists, on the other hand, claim that compact cities are more sustainable. The advantages of compact urban areas are listed as having fewer cars per capita, low emissions, low energy consumption, better public transportation services, increased accessibility overall, the repurposing of infrastructure and previously developed land, high quality of life, the preservation of green space, and a business-friendly environment (Elkin et al., 1991; Engwicht, 1992; Jacobs, 1961; McLaren, 1992). The findings of this thesis, which evaluated how urban environmental factors affect air quality and childhood asthma in four regions of Ankara, demonstrate that the centrists' point of view seems to be valid.

In light with the thesis findings, in order to create environments where air pollution will be less, as city planners, we should create compact urban areas, design walkable urban environments with a diverse land-use and effective public transit systems. Planners should consider implementing these policies both in newly developed areas and in the transformation of the current neighborhood environments.

This thesis found that the presence of residential environments with low land-use mix and active green open spaces, with a high automobile traffic and close proximity to industrial areas negatively affect outdoor air quality and childhood asthma. This finding indicates that designing compact urban environments, creating high amounts of open and green areas inside the neighborhood environments, finding solutions to prevent high traffic volume, and planning industrial areas away from the residential areas are crucial in creating healthy cities.

Although these issues are not new and highly known in the City Planning profession (as assumptions), this thesis demonstrates the significance of these problems and scientifically validates our previous assumptions about the relationship between urban environment, outdoor air quality and childhood asthma.

6.2 Contributions and Limitations of the Study

The relationship between urban environment, outdoor air quality and childhood asthma is a multidisciplinary relationship that should be investigated collaboratively with other professions. The fact that the study was carried out in an interdisciplinary manner with the mentoring of an environmental engineer and a medical doctor specializing in pulmonary diseases can be considered as one of the contributions of this thesis to the existing literature dominated by studies conducted by medical doctors or researchers. Also this study propose a novel methodology in terms of investigating the relationship between urban environment, outdoor air quality and childhood asthma.

As far as we know, this study is the first study aimed at investigating the relationship between meso-scale urban environment characteristics, outdoor air quality and childhood asthma. While the relationship between urban environment and outdoor air quality has been previously studied by city planners, usually from a macro-scale perspective, to the best of the author's knowledge, this is the first study that aims to investigate this relationship from a meso-scale perspective in a developing country, Turkey, and that aims to link the findings to childhood asthma from a planner's point of view. As emphasized previously, a review of the literarure on this topic shows that none of the authors of the previous studies on the relationship between urban environment and childhood asthma had an urban planning affiliation

To the best of author's knowledge this study is also the first to consider the role of a variety of urban environment characteristics on outdoor air quality and childhood asthma. In addition, it is the first study that investigates the relationship between figure-ground and outdoor air quality, which was found to be correlated in each buffer size with PM concentration.

As mentioned in Chapter 3, before the initiation of the field work, the author helped design a large-scale project aimed at collecting primary data from children regarding their asthmatic status (via an ISAAC survey) and data from passive sampling to understand the NOx and NO2 values in different urban spots. The author helped in the writing of a grant proposal to fund her thesis study. Although TÜBİTAK accepted to fund the project, as mentioned previously, the pandemic coincided with the data collection process, which led the author change the research design to finalize this study in a restricted time period. This necessitated the author to use secondary data to examine the levels of asthma in children or only focus on PM values by using PM tracking devices.

During the research process, the author experiences a variety of barriers for designing a research that yiels valid results. Obtaining address-based health data in Turkey is extremely challenging. As a matter of fact, within the scope of this thesis, addresses of children with asthma could not be obtained. The Ministry of Health did not share the residential addresses of child patients for ethical reasons (i.e., protection of the rights of the child). Thus, the rates obtained based on children registered in family public health centers were generalized to the study area. This limitation prevented a point-based analysis of the urban environment, air quality and childhood asthma within the parameters of this study.

The effects of the microclimatic conditions of the urban open spaces (like heat islands, wind corridors, etc.) on outdoor air quality required the author to measure the climate at the street scale by using devices like climate meters. However, within the scope of this thesis, estimations about the study area were used based on station data. The author acknowledges the fact that it was possible to choose the neighborhood units around the meteorological stations to increase the validity of the findings regarding meteorology, but as it was explained previously, the COVID-19 pandemic affected the research design of this study; the author had already chosen the neighborhoods before the pandemic.

Lastly, data for the traffic volume was created in ArcGIS by referring to the images received from Yandex Maps based on the forecasts for the specific days and times of the air quality measurements. The data of the roads on the measurement dates could not be investigated since Yandex Maps, or any other database could not provide historical data. This was a limitation of the thesis.

6.3 Implications for Future Research

There are secondary data used in the thesis, as mentioned in the limitations section. Using primary data instead of secondary data will give more accurate results in further research. Working with address-based health data will produce more precise outcomes. Furthermore, using climate meters together with street-based air quality measurements and collecting street-based climate data will lead to more accurate results in cross-case studies. Finally, obtaining traffic data on the same dates as air quality measurements will give more accurate results to researchers in understanding the relationship between traffic volumes and outdoor air quality.

As a finding of this thesis, in future studies, outdoor air quality measurements should be used while investigating the relationship between urban environment and childhood asthma.

The SPSS analysis within the scope of this research looks at linear relationships. Urban environment variables may not have a linear relationship with pollutant concentrations, so nonlinear methods can be tried in further studies. Since the author did not control for some built environmental variables that may affect the PM concentrations (e.g., buffers that have low greenness index and high solid/void ratios versus high greenness index and high solid/void ratios) in her research design, one should be careful with interpreting the findings of this research. The author, once again, notes that this is the first study aimed at linking childhood asthma to outdoor air quality and urban environmental characteristics (or vice versa). Future research may increase the validity of the findings presented here, not only by changing the data collection techniques (like for example using passive sampling for monitoring street-level air quality), but also by, for example, controlling the variables during data analysis.

As a last comment, Macintyre et al. (2002) noted that ‘‘rather than there being one single, universal ‘area effect on health,’ there appear to be some area effects on some health outcomes, in some population groups, and in some types of areas’’. Therefore, a study conducted in one city may not be generalizable to other cities, and each city or even each neighborhood should be investigated independently.

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APPENDICES

A. List of Terms and Their Definitions

Terms Related to Urban Environment

Mesoscale: Meso scale is used to describe small-scale areas where people live, such as a neighborhood or census block group.

Urban Environment: Urban environment, as is used in this thesis, refers to the physical (natural and built) characteristics of urban areas.

Natural Environment: Natural environment refers to geographical, meteorological characteristics of studied areas.

Built Environment: Built environment represents human made environments such as buildings, streets, park areas etc.

Slope Analysis: It is a topographic map created with altitude values.

Figure-Ground Analysis: It is an analysis that is used to illustrate the relationship between built and unbuilt (solid and void) space in cities.

Building Density Analysis: It is calculated by multiplying the surface area of the buildings with the number of floors divided by the studied regions.

Land-use Mix Analysis: It is an analysis that used for understanding how many different building uses are existing in the studied areas.

Open and Green System Analysis: It is simply the calculation of the open and green areas in the studied neighborhoods.

Street Connectivity Analysis: It is an analysis which used to understand how connected the streets are in studied areas.

Traffic Volume Analysis: It is the analysis to measure what is the traffic volume in the roads and streets in studied areas.

Terms Related to Air Quality

PM (Particulate Matter): It is an air pollutant which varies in its composition and size, and is usually classified into 3 size groups: coarse particles (PM10, diameter <10 and ≥ 2.5 μm), fine particles (PM2.5, diameter <2.5 μm), and ultrafine particles (<0.1 μm). It originates from combustion and noncombustion sources including industrial sources, tailpipe emissions, brake and tire wear, resuspended soil and dust, wildfires and prescribed burns, and agricultural, biomass, and coal burning.

Terms Related to Health

Childhood Asthma Prevalence: It is the proportion of the child population with asthma. It is different from childhood asthma incidence. Incidence refers to new cases only whereas prevalence refers to all cases.

B. Supporting Tables for Literature Review

Table B.1. Literature on the relationship between urban environment and outdoor air quality

Article	**Study Area**	**Urban Environment Characteristic**	**Pollutants Measured**	**Key Findings**
(Stone, 2008)	45 large US metropolitan regions in 2000	Centeredness, connectivity, density, land use mix, sprawl index	NOx, VOC, O3, NO2	Density is correlated with NOx and VOC emissions. Centeredness, connectivity, density, and sprawl index are correlated with O3.
(Bechle et al., 2011)	83 cities around the world in 2005-2007	Population, income, contiguity Index, Compactness Index, harmonic mean dilution rate	NO2	Population(log), Income, and Contiguity Index are correlated with pollution.
(Clark et al., 2011)	111 US cities from 1990 to 2010	City shape (elongation ratio), Jobs-housing imbalance, population centrality, population density, road density, transit supply, Vehicle Kilometers of Travel, income, land area	O3, PM2.5	Population centrality, population density, and transit supply are correlated with pollution.
(Bereitschaft & Debbage, 2013)	86 US metropolitan areas in 2000	Urban continuity, urban shape complexity, residential density, land use mix, degree of centering, street accessibility,	O3, PM2.5, VOCs NOx PM2.5 CO2	Residential density, street accessibility, Lopez & Hynes Index, and USA Today Sprawl Index are correlated with O3 or PM2.5 concentrations. Urban continuity, urban shape complexity, residential density, degree of centering, street accessibility, and SGA Sprawl Index are correlated with non-point source emission.
(McCarty & Kaza, 2015)	All US counties in 2006	Total urban area, number of patches, total land area, mean urban patch area, Std. dev. of urban patch area, Eccentricity of Standard Deviation Ellipse, tota l forest area,	PM2.5, O3, and AQI	Total urban area, number of patches, total land area, mean urban patch area, Eccentricity of Standard Deviation Ellipse, total forest area, urban forest mixing, population, median income, centrality, the proportion of industrial

		urban forest mixing, population, median income, centrality, the proportion of industrial employment, mean summer temperature, precipitation		employment, mean summer temperature, and precipitation are correlated with air pollution.
(She et al., 2017)	30 cities in Yangtze River Delta, China, 1990-2015	Patch Area, number of urban patches, largest patch index, road network density, mean perimeter-area ratio	Carbon emission.SO2, NO2, PM10, PM2.5, CO, O	Patch Area, number of urban patches, largest patch index, road network density, and mean perimeter-area ratio are correlated with carbon emission. Patch area, number of urban patches, and mean perimeter-area ratio are correlated with air pollution.
(Lu & Liu, 2016)	217 China Cities in 2009	The fractal dimension index, Boyce-Clark Shape Index, compact ratio index, population, per capita GDP, population density, industrial output per square kilometer, annual precipitation, relief degree of land surface	NO2, SO2	X'- or 'H'-shaped cities in northern or central China have less air pollution. The compact ratio index, population, per capita GDP, population density, industrial output per square kilometer, annual precipitation, and relief degree of land surface are correlated with air pollution.
(Cárdenas Rodríguez et al., 2016)	249 Large Urban Zones across Europe in 2006	Highway density, road access, population density, the share of agriculture in the added value, the share of industry in added value, the share of artificial area, the share of agricultural area, wetland share, forest share, number of fragments	NO2, PM10, SO2	The built-up area and the fragmentation of the city are positively correlated with NO2 and PM10. Population density is positively correlated with SO2.
(Y. Liu et al., 2017)	30 China cities in 2000, 2007, and 2010	Urban elongation ratio, urban compactness ratio, built-up green coverage, power consumption, SO2 emissions, gross value of industrial output, buses per million people, urban population, heating system, built-up area	PM10, AQI	Urban elongation ratio, urban compactness ratio, built-up green coverage, power consumption, SO2 emissions, the gross value of industrial output, and buses per million people are correlated with urban smog.

Table B.1 continued

(Yuan et al., 2018)	157 China cities in 2015	Density, centering, mix, accessibility, complexity, continuity, population, precipitation, wind, GDP, Indus-Emission.	PM2.5, PM10, NO2, SO2, CO, O3	Density, centering, mix, accessibility, continuity, precipitation, wind, and Indus-Emission are correlated with PM2.5 concentration. Density, centering, accessibility, continuity, precipitation, wind, Indus-Emission, and GDP are correlated with PM10 concentration. Complexity, population, precipitation, Indus-Emission are correlated with NO2 concentration. Centering, accessibility, continuity, precipitation, Indus-Emission, and GDP are correlated with CO concentration. Centering, accessibility, precipitation, and Indus-Emission are correlated with SO2 concentration. Density and Indus-Emission are correlated with O3 concentration. Cities with increased population density have better air quality than those with decreased population density.
(Borrego et al., 2006)	Three imaginary cities (Disperse, Corridor, Compact)	Density, residential, commercial or industrial uses, car use dependence, urban sprawl, Area categories (rural, green, suburban, and urban)	NOx, VOC, O3	The Corridor City is characterized by the highest emission rates, while the Disperse City demonstrates the lowest emissions per area, and the Compact City is characterized by lower emission rates per inhabitant. According to the photochemical simulations performed, it is possible to conclude that compact cities with mixed land use provide better air quality compared to disperse cities with lower densities and segregated land use or network cities equipped with intensive transport structures.
(Fan et al., 2018)	344 prefecture-level cities in China (excluding Hong Kong, Macao, Taiwan, and	Six urban form variables population density, elongation ratio (ER), urban compactness ratio (CR), aggregation index (AI), landscape shape index (LSI), number of the patch (NP), largest urban patch index	CO, NOx, SO2, PM2.5	Higher urban compactness and less fragmentation remarkably affect urban pollution reduction. A high population density will significantly reduce NOx emissions, though it will generally increase SO2 emissions.

Table B.1 continued

	Nansha islands, 2010	(LPI), and mean urban patch area (MN_PA)		
(Stone et al., 2010)	11 US cities, 2000-2050	Population Density, Vehicle Miles of Travel, Vehicle Emissions, number of households, median household income, mean vehicles per household, and employment rate	CO, CO2, NOx, PM2.5, VOC	Compact development patterns, when instituted over a significant period, can measurably reduce vehicle travel and pollutant emissions at the scale of the metropolitan region.
(Bereitschaft, 2011)	86 metropolitan-scale areas and 19 megapolitan areas within the conterminous United States 1998-2002	Sprawl indices, nine spatial metrics (edge density, largest patch index, area-weighted mean shape index, landscape shape index, area-weighted mean patch fractal dimension, contagion, clumpiness index, contiguity, and percentage of like adjacencies)	O3, VOCs, NOx, PM2.5, PM10, CO2	The urban form has a measurable impact on both the non-point source emission and ambient air pollution concentration. Urban areas that exhibited more “sprawl-like” urban forms (i.e., lower residential density, less street network connectivity, less contiguous urban development) generally had higher non-point source emissions and/ or ambient air pollution concentrations.
(Taseiko et al., 2009)	The city of Krasnoyarsk (in Eastern Siberia)	building density, building heights and the permeability of building arrangements relative to wind flow, distribution of pollutant concentrations off roadways	non	Permeability and building density are necessary parameters for accurately modeling urban air pollution and influencing regulatory requirements for building planning.
(Bouhamra & Abdul-Wahab, 1999)	Mansouriya residential area in Kuwait	Traffic-related air pollution	CO, NO, NO2, SO2	It was found that the levels of air pollutants in the Mansouriya residential area are low compared to the US EPA standards. However, relatively high levels of pollution are seen during rush hours.
(Zwack et al., 2011)	Manhattan, New York	Traffic-related air pollution	UFP, PM 2,5	An approximate 11% increase in concentrations of UFP and an 8% increase in concentrations of PM2.5 over urban background was estimated

				during high-traffic periods in street canyons as opposed to low-traffic periods.
(Liu et al., 2021)	Wuhan, China	Land use, building density, wind	PM2,5, CO	The results suggest that the urban form of the podium-level porosity can be set higher than 0.7 to promote the ventilation of street-level PM2.5 and CO, building density can be less than 0.35, and the standard deviation of height can be set to ~10 m in central Wuhan to mitigate street-level PM2.5.
(Dionisio et al., 2010)	Four Communities in Accra, Ghana	Four different neighborhoods with different socioeconomic status	Pm2,5, PM10	The geometric means of PM2.5 and PM10 along the mobile monitoring path were 21 and 49 μg/m3, respectively, in the neighborhood with the highest SES and 39 and 96 μg/m3, respectively, in the neighborhood with the lowest SES and highest population density.
(Qu et al., 2019)	Shenyang, China	Urban parks and traffic	Pm2,5, PM10	Changes in PM10 and PM2.5 under sunny and windless conditions showed significant positive correlations with traffic flow rates ($p < .01$). PM10 and PM2.5 levels also varied significantly among monitoring locations that were proximal or distant to parklands, with marked reductions in both PM10 and PM2.5 levels close to parks.
(Spirn, 1986)	non	Major street or highway (especially with parking lanes), Busy intersection, Taxi Stand, Bus Depot, Parking garage entrance, and exhaust vents, a Tunnel entrance, and exhaust vents, Proximity to the road, Winds (Wind shadows at leeward base of buildings, Short street canyons blocked at both ends, Long street canyons perpendicular to prevailing	non	What works in one city may be inappropriate or impractical in another. Whatever its particularities, however, a plan to address air pollution should always acknowledge the issues of energy conservation and climatic comfort. Increased air pollution is often the by-product of profligate energy use. Promoting climatic comfort in outdoor spaces may contribute to decreased air circulation and air pollutants accretion. For example, deep arcades protect sidewalks and building entrances with

Table B.1 continued

		winds, Urban districts with narrow, irregular street patterns), Breezes (Locations upwind of pollution source, Windward base of obstruction to breeze), Inversions (Valley bottom, Street canyon bottom), Spatial enclosure (High, narrow street canyons, Street side arcade, Bus shelter, Interior atrium, Tunnel, Parking garage)		vehicular access or ds that might ventilate a space reflected from it.

Table B.2. Literature on the relationship between outdoor air quality and childhood asthma

Article	Study Area	Pollutants Measured	Detect Asthma	Unit of Analysis	Key Findings
(Iskandar et al., 2012)	Copenhagen	ultrafine particles (UFPs), PM10, PM2.5, NOx, NO2	Hospital database	Daily counts of admissions for asthma in children aged 0-18 years to hospitals located within a 15 km radius of the central fixed background urban air pollution measurement station in Copenhagen between 2001 and 2008	A significant association was found between hospital admissions for asthma in children aged 0-18 years and NOx, NO2, PM10 and PM2.5, there was no association with UFPs. The association was stronger in infants than in older children for all pollutants, but no statistically significant interaction was detected.
(Pénard-Morand et al., 2010)	six French communities (Bordeaux, Clermont-Ferrand, Cre´teil, Marseille, Strasbourg, and Reims)	PM10, VOCs	ISAAC questionnaire, skin prick tests	The sample was taken from all pupils in the 401 relevant classes from 108 schools randomly, 4,907 children with asthma who had resided at their current address for the past 3 yrs.	For children residing at their current address for 3 years, the risk for suffering from asthma, eczema, allergic rhinitis and sensitization to pollens was significantly higher in neighborhoods of schools with higher concentrations of some of the major urban pollutants, mainly influenced by traffic emissions. The associations of lifetime asthma with benzene and PM10 are particularly robust because they remain significant even among children residing at their current address since birth. Among these same children, the associations of sensitization to pollens with VOC and PM10 reached borderline significance.

Table B.2 continued

(Sunyer et al., 1997)	Barcelona, Helsinki, Paris, and London	O3, SO2, NO2,	Hospital database	non	Daily admissions for asthma in adults increased significantly with increasing ambient levels of nitrogen dioxide and non-significantly with particles measured as black smoke. The association between asthma admissions and ozone (O3) was heterogeneous among cities. In children, daily admissions increased significantly with sulfur dioxide (SO2) and non-significantly with black smoke and NO2, though the latter only in cold seasons. No association was observed for O3. The associations between asthma admissions and NO2 in adults and SO2 in children were independent of black smoke.
(Zora et al., 2013)	El Paso	PM2.5, PM10, BC (Black Carbon), NO2, benzene, and toluene	Questionnaire	2 elementary schools- School 1 is located in a "high traffic" area within 300 ft of principal arterial or high-service, capacity-controlled access roadways, with heavy truck traffic. School 2 located in a "low traffic" area adjacent to local surface streets exclusively	In the main single- and two-pollutant epidemiologic models, authors found non-significant, albeit suggestive, positive associations between ACQ scores and PM10, PM10–2.5, PM2.5, BC, NO2, benzene, toluene, and ozone.
(Hadley et al., 2018b)	New York	CO, NO2, SO2, PM2.5, PM10	Global databases	non	Reductions in both HAP (Household air pollution) and OAP (Outdoor air pollution) exposures would significantly increase life expectancy in the United States and abroad. Clinicians can play a significant role in mitigating pollution - attributable cardiovascular risk among the patients they serve. We have outlined a clinical approach for improving cardiovascular health. Clinicians, in partnership with

Table B.2 continued

					government agencies, can use this approach to reduce pollution exposures in their service populations. We encourage clinicians and other health professionals to tailor this model to their specific populations and to collect prospective data to validate the efficacy of screening tools and interventions.
(Maluleke & Worku, 2009)	Polokwane, in the Limpopo in South Africa	SPM (Suspended PM)	ISAAC questionnaire	A random sample of 742 school children between 13-14 years in Polokwane, Limpopo Province.	The presence of smoke in the environment was strongly associated with asthma. Environmental air pollution is an important risk factor for asthma in children.

Table B.3. Literature on the relationship between URD and childhood asthma

Study	**Context**	**Characteristic of Urban Environment**	**Detect Asthma**	**Measuring Pollutants**	**Results**
(Forastiere et al., 1992)	3092 primary school children (1137 participants from urban areas, 977 participants from industrial areas, and 978 participants from rural areas) - Italy	*Rome (urban) polluted mostly by automobile exhaust and heating systems *Civitaveccia (urban-industrial) polluted by three oil-fired thermoelectric power plants *Viterbo (rural)	Questionnaire adapted from the American Thoracic Society	No Pollution data	The frequency of most outcome variables among schoolchildren from the polluted areas (urban-industrial) was higher than among those growing up in the nonpolluted area (rural).
(Nystad et al., 1997)	School children in the first to ninth grade, 6-16 years old (2577 participants from urban areas, 1177 participants from rural areas, and 831 participants from industrial-coastal areas) - Norway	*Oslo (urban) 1130,1 person per km² *Upper Hallingdal (rural) 2,9 person per km² *Odda (Industrial, coastal) 5,1 person per km²	ISAAC-questionnaire	No Pollution data	The results do not support the hypothesis that respiratory morbidity is more common in urban than rural areas. The main findings are that there are minor differences in the parent-reported prevalence of respiratory symptoms and asthma between the urban and the rural area, while the prevalence rates were lowest in the coastal area. The lifetime prevalence of asthma was lowest in Odda (5.4) compared to Oslo (9.4) and Hallingdal (8.5).
(Yemaneberhan et al., 1997)	9844 participants in the urban group and from 3032 in the rural group (Not just children but writers	Urban and Rural areas in Jimma	Questionnaire	No Pollution data	All respiratory symptoms were rare in children and were significantly less common overall in the rural than in the urban group.

	evaluate results in terms of age groups) - Ethiopia				
(SIDRIA, 1997)	18,737 schoolchildren aged 6–7 yrs, from eight centers - Italy	Eight centers of northern and central Italy. The writers characterized the centers as metropolitan, urban, or urban/rural.	ISAAC questionnaire and hospital admission data	No Pollution data	According to questionnaire data, an increased level of urbanization is more likely to produce chronic airway irritation than asthmatic disorders. On the contrary, the prevalence of physician-diagnosed asthma increased with the level of urbanization.
(Odhiambo et al., 1998)	4th-grade school children (568 children from urban, 604 children from rural) - Kenya	*Nairobi (Urban) *Muranga (rural)	Questionnaire	No Pollution data	In both males and females, all symptoms associated with asthma were more frequent in urban than in rural children, despite the fact that rural children were more frequently exposed than their urban counterparts to cigarette smoke and pets in the home, both of which are recognized environmental risk factors for childhood asthma.
(Ranzi et al., 2004)	6-11-year-old school children (118 children in total. 67 children from urban-industrial and 51 from rural areas) - Italy	*Casalgrande (urban-industrial) *Sassuolo (urban-industrial) *Castelnuovo Monti (rural) *Pavullo (rural)	Questionnaire and daily dairy for 12 weeks	Stationary data - PM2,5, NO2, and CO.	Symptom prevalence was higher in the urban-industrial area than the rural area; the most frequent symptoms were cough, phlegm, and stuffed nose.

Table B.3 continued

(Hirshon et al., 2006)	Asthmatic children less than 18 years old. - USA	They divide Maryland counties as city, suburban and rural	They use Emergency Department (ED) visits from April 1997 through March 2001 – Hospital database	No Pollution data	area with high rates of poverty) had the highest rates of asthma visits, adjusted odds ratios identified the wealthiest suburban county to have a higher risk of an asthma ED (emergency department) visit. Children from rural counties, for the most part, had fewer ED asthma visits than children from urban and suburban counties.
(Renzetti et al., 2009)	37 untreated allergic seven years old school children with mild persistent asthma - Italy	An urban and rural area in Pescara (Children recruited from a highly polluted urban environment and relocated to a less polluted rural environment - real-life experiment)	Asthma Clinic of the Department of Pediatrics of the Civil Hospital in Pescara's database	Stationary data for urban area, and a mobile station for rural area (PM10, CO, NO2, O3, Benzene)	Better air quality in rural area is associated with a rapid reduction of airway inflammation in allergic asthmatic children.
(Pesek et al., 2010)	10,895 urban children and 1,190 rural children - USA	*Little Rock School District (Urban) *Marvell and Eudora school districts (rural) Arkansas	Questionnaire, Hospital database	No Pollution data	Asthma prevalence was similar between representative rural and urban groups in Arkansas, but asthma morbidity was significantly higher in the rural group. No significant differences in emergency department visits or hospitalizations between the urban and rural groups.

Table B.3 continued

(Kolokotroni et al., 2011)	4944 school children participated in the 2000 survey and 2216 school children in the 2008 survey (In total, 71 schools (40 urban and 31 rural) in Nicosia and 56 schools (33 urban and 23 rural) in the Limassol - Cyprus	The place of residence was characterized as urban if the family address was (a) within the boundaries of the metropolitan areas of Nicosia or Limassol (the two largest cities on the island) or (b) in any of the municipalities in suburban areas that are in geographic continuity with the inner city	ISAAC-questionnaire	No Pollution data	The prevalence of most asthma and allergy outcomes appeared increased in both urban and rural areas by the year 2008 compared to year 2000. However, in the case of asthma and allergic rhinitis outcomes rises to appear more pronounced in the rural than the urban areas

Table B.4. Literature on the relationship between TRAP and childhood asthma

Study	**Context**	**Characteristic of Urban Environment**	**Detect Asthma**	**Measuring Pollutants**	**Key Findings**
(Wjst et al., 1993)	6537 fourth-grade children (aged 9-11 years) in Munich - Germany	Automatic induction loops obtained census data on car traffic on main streets. Cars on smaller streets were counted over 24 hours and a few over eight hours.	Questionnaire and Lung Function Test	On the roads, permanent multicomponent air monitoring stations have been installed at a height of 3 meters in the city. Writers take 250 measurements distributed over the city. (CO, benzene, O^3, NO^2)	High rates of road traffic diminish forced expiratory flow and increase respiratory symptoms in children. There were no significant changes in the prevalence of asthma, recurrent bronchitis, and hay fever.
(Oosterlee et al., 1996)	673 adults and 106 children (0-15 years) living along busy traffic streets in the city of Haarlem was compared with a control sample of 812 adults and 185 children living along quiet streets. - Netherlands	Writers select busy roads using environmental traffic maps, which display the estimated noise and air pollution levels of each traffic street in the region.	Questionnaire	Pollution levels are estimated with a mathematical model (calculation of air pollution by road traffic (CAR) model). In this model, predicted levels of air pollution are calculated for a certain distance from the axis of the road (NO^2)	Children living along busy streets were found to have a higher prevalence of most respiratory symptoms than children living along quiet streets.
(van Vliet et al., 1997)	1068 school children - Netherlands	Writers point each child's home and school. They measure the distance of homes to freeways. Also, take the traffic counts from the Ministry of Public Works.	Questionnaire (derived from questionnaires developed by WHO)	Pollutants were measured at four different distances from the freeway. In Delft, sites were located at 15, 115, 165, and	Cough, wheeze, runny nose, and doctor-diagnosed asthma were significantly more often reported for children living within 100 m of the freeway.

Table B.4 continued

				freeway's edge. In Rotterdam-Overschie, sites were located at 32, 82, 133, and 260 m from the freeway. (PM10, PM2.5, black smoke, NO²)	and the concentration of black smoke measured in schools were found to be significantly associated with chronic respiratory symptoms.
(English et al., 1999)	5,996 children <14 years of age who were diagnosed with asthma in 1993 and compared to a random control series of nonrespiratory diagnoses (n = 2,284) - USA	Writers used a database for average daily traffic flow data. To capture traffic flow, they encircle 168,8 m (550-ft) buffer in each child's home.	A health database has been used to choose children with asthma and control group	No pollution data	Asthmatic children living near busy roads may have an increased risk of repeated medical care visits compared to asthmatic children living near lower traffic flows. This suggests that higher traffic flows may be related to an increase in severity or number of asthmatic symptoms requiring repeated medical visits in asthmatic children. Repeated exposure to particulate matter and other air pollutants from traffic exhaust may aggravate asthmatic symptoms in individuals already diagnosed with asthma.
(Wilkinson et al., 1999)	5-14 years old emergency admissions (n = 1380) or all respiratory illness including	Coordinates of the place of residence of children were pointed. Measures of exposure to traffic were: (1) simple Euclidean distance to	Health database	No pollution data	No association between the risk of hospital admission for asthma or respiratory illness among children aged 5–14 and proxy

Table B.4 continued

	asthma (n = 2131), and controls (n = 5703) were other emergency admissions excluding accidents - UK	nearest main road; (2) distance to nearest road with a modeled peak hour traffic volume exceeding 1000 vehicles/hour; (3) computed traffic volume (vehicle-meters/hour) along roads within a radius of 150 m of the postcode centroid.			markers of road traffic pollution.
(Venn et al., 2000)	22 968 primary and 27 826 secondary school children - UK	Writers defined a 1 km2 square around the schools and analyzed within this square. They use a traffic activity index (TAI). They measure the flow with portable Marksman Systems for the roads in the vicinity of the schools. Other roads data either collected or estimated	Questionnaire	No pollution data	Asthma in children show no significant positive relation with TAI. Positive but non-significant dose-related effects of traffic activity on wheeze severity in primary and secondary children and on the persistence of wheeze in the longitudinal cohort.
(Bente et al., 2009)	2871 of 9- to 10-year-old children residing in Oslo - Norway	Distance to major roads from residence addresses	Questionnaire	The model to estimate NO^2 was based on prospectively collected data on emissions for several time periods, hourly meteorological measurements, topography, and detailed background air pollution concentrations measured at regional background	No positive associations of long-term traffic-related exposures with asthma onset or with current respiratory symptoms in 9- to 10-year-old children in Oslo.

Table B.4 continued

				stations in the southern part of Norway. (NO^2)	
(Friedman et al., 2001)	Children aged 1 to 16 years who resided in the five central counties of metropolitan Atlanta - USA	*Hourly traffic data collected by the Georgia Department of Transportation *Total number of passenger trips collected per day on Atlanta's public buses and rail lines during the study period *Total gallons of gasoline purchased in the state	Health database	Stationary Data (CO, PM10, O^3, NO^2, SO^2)	Efforts to reduce downtown traffic congestion in Atlanta during the Olympic Games resulted in decreased traffic density, especially during the critical morning period. This was associated with a prolonged reduction in ozone pollution and significantly lower rates of childhood asthma events. These data support efforts to reduce air pollution and improve health via reductions in motor vehicle traffic.

Table B.4 continued

(Gauderman et al., 2005)	208 children from 10 southern California communities - USA	*Traffic volume on roadways within 150m, *Residential distance to the nearest freeway *Model-based estimates of pollution from nearby roads.	Writers choose children with asthma from another study. Also made a questionnaire with the subject's parent	NO^2 was sampled with Palmes tubes outside of each children's home (NO^2)	A lifetime history of doctor-diagnosed asthma was associated with outdoor NO2 and also observed increased asthma associated with closer residential distance to a freeway and with model-based estimates of outdoor pollution from a freeway. Asthma was not associated with traffic volumes on roadways within 150 meters of homes or with model-based estimates of pollution from non-freeway roads.
(J. J. Kim et al., 2004)	1,571 school children in 64 participating classrooms in the ten schools - USA	The study area was comprised of 10 neighborhoods that span a busy traffic corridor. School sites were selected to represent a range of locations upwind and downwind of major roads. Writers also used proximity to busy roads.	Questionnaire	*PM10 and PM2.5 mass concentrations were measured using filter-based samples, whereas BC concentrations were determined on the PM10 filter samples using an established light attenuation method. *NOX and NO^2 concentrations were determined with passive diffusion samplers. *Measurements made at school	Results support the hypothesis that traffic-related pollution is associated with respiratory symptoms in children. For children residing at their current address for at least one year, writers found modest but significant increases in the odds of bronchitis symptoms and physician-diagnosed asthma in neighborhoods with higher concentrations of traffic pollutants.

				sites (PM10, PM2,5, NOx, NO², and black carbon (BC)(	
(Lewis et al., 2005)	11562 school children aged 4–6 years in 235 schools - UK	The distance between the children's house and the main road. Writers divide the distance as nearer than 30m, between 30 and 89 m, between 90 and 149m, and more than 150m.	ISAAC questionnaire	No pollution data	Asthma prevalence in children was not associated with the proximity of the home to a main road.
(Michael et al., 2008)	217 children 10–18 years of age - USA	Subjects were selected randomly from the larger cohort based on different levels of traffic-related exposure. Specifically, writers divided subjects into two strata (above and below the median traffic exposures within each community) and then randomly selected an equal number from each strata.	Writers exclude children with prevalent asthma from another study. Also made a questionnaire with the subject's parent.	NO² was sampled with Palmes tubes outside of each children's home's front or back yard. (NO²)	Markers of traffic-related air pollution were associated with the onset of asthma. The risks observed suggest that air pollution exposure contributes to new-onset asthma. Study found significant associations between incident asthma and measured outdoor residential exposure to NO2.
(Nicolai et al., 2003)	Random samples of school children (n=7,509) - Germany	Average daily traffic counts for all streets taken from the city administration. By setting a distance limit of 50 m around each child's home, writers identified all street segments with traffic counts within	ISAAC questionnaire also skin-prick tests, blood sampling, lung function testing, and bronchial challenge	Writers took measurements of yearly average concentrations of traffic-associated pollutants at 18 heavy traffic sites in the city and from 16 low-to-medium traffic	Traffic counts were associated with current asthma, wheeze, and cough. High vehicle traffic was associated with asthma, cough, and wheeze, and in children additionally exposed to

Table B.4 continued

		this distance, and the sum of their daily traffic counts was used to characterize traffic exposure for a child.		sites from another study.(benzene, soot and NO^2)	environmental tobacco smoke, with allergic sensitization.
(Perez et al., 2012)	Los Angeles County for the year 2007 for children < 18 years of age. - USA	Writers code each child's home and take the distance to the nearest freeway or major road. Residential distance to the major roads categorized as < 75 m	ISAAC questionnaire	Stationary Data (NO^2, O^3)	Writers estimated that 27,100 cases of childhood asthma (8% of total) in LAC were at least partly attributable to pollution associated with residential location within 75 m of a major road. As a result, a substantial proportion of asthma-related morbidity is a consequence of near-roadway pollution, even if symptoms are triggered by other factors.
(Portnov et al., 2012)	3922 school children. Writers choose children who live less away than 500 m from one of the air quality monitoring stations. - Israel	The proximity of main roads to residences. A residence closer than 50 m to a main road’s longitudinal axis was conditionally defined as a high exposure area; otherwise, it was defined as a low exposure area.	Health database	Stationary Data (PM10, SO^2)	The analysis reveals that childhood asthma in the study area appears to be significantly associated with PM10. Proximity to the main road variable did not emerge as statistically significant.
(Rob et al., 2006)	4,762 school children 5-7 years of age in southern California - USA	Writers code each child's home and take the distance to the nearest freeway or major road. Residential distance	ISAAC questionnaire	No pollution data	Residence within 75 m of a major road was associated with an increased risk of lifetime asthma, prevalent asthma, and

Table B.4 continued

		to the major roads categorized as < 75 m, 75–150 m, >150–300 m, and > 300 m			wheeze. The higher risk of asthma near a major road decreased to background rates at 150–200 m from the road.
(Sahsuvaroglu et al., 2009)	Children in grades one and eight in Hamilton, Canada, in 1994–95 (N ~1467) - Canada	One of the models to estimate the pollutants was to create buffers of 50 m and 100 m from major roadways to proxy for traffic pollution exposure. Children living within the specified buffer distance from a major road were assigned the number 1; those who did not were assigned the number 0.	ISAAC questionnaire	Writers used four different models to estimate pollution levels. (PM10, O^3, NO^2, SO^2, Nox)	There were no significant associations between any of the exposure estimates and asthma in the whole population, but traffic-related pollutants, such as NO2, are associated with asthma without overt evidence of other atopic disorders among female children living in a medium-sized Canadian city.
(Skrzypek et al., 2013)	5733 school children between 2003–2004 in Bytom (the most industrialized and densely inhabited region) - Poland	They point to each children's home. They use three models for traffic data. – Model A: the distance of a child's residence to major road (≤ 100 m and > 100 m), – Model B: the highest traffic count within a 100 m radius of the place of residence (> 90th percentile and ≤ 90th percentile of traffic counts), – Model C: the traffic density within	ISAAC questionnaire	No pollution data	A statistically significant association was found between doctor-diagnosed asthma and residential proximity to traffic. The study findings suggest that even in an area with poor regional ambient air quality, adverse respiratory health outcomes are more frequent in children living in proximity to the high vehicle traffic flow.

Table B.4 continued

		a 100 m radius of the place of residence			
(Spira-Cohen et al., 2010)	Four schools for data. Two of them near highways, two of them not. Four schools 10 asthmatic children in each school. A total of 40 asthmatic children. - USA	Traffic counters to count the vehicles. Traffic counters recorded vehicle numbers by vehicle class, which were then divided into car and truck categories, and tabulated by 15-min interval counts.	Health database	Writers collect the air quality data in 2 ways. One placing devices in schools and one placing devices in children's backpack (PM2.5)	Traffic, and especially smoke emitted from diesel vehicles, is a significant contributor to personal PM exposure levels in children living in urban areas such as the South Bronx, NY, many of whom suffer from asthma and may be particularly susceptible to health effects from these exposures.
(Svendsen et al., 2012)	1529 school children in the El Paso, Texas- USA	Writers use both school and residence-based exposure estimates. They use a prediction model that included elevation, distance to the nearest border crossing, distance to the nearest petroleum facility, population density of the census tract, distance to the nearest roadway with a traffic volume greater than 90,000 vehicles per day, and traffic intensity within 1,000 m.	American Thoracic Society children's questionnaire.	Passive monitoring network at school areas and also stationary data. (NO^2 and Volatile Organic compounds (VOC)	The study found that increasing exposure to indicators of traffic-related air pollution was associated with significant decrements in lung function among El Paso schoolchildren. Among the children attending the upland schools, we observed associations between GIS-modeled exposure to traffic-related air pollutants and both asthma and

Table B.4 continued

					bronchitis in the last year.
(Zmirou et al., 2004)	f 217 pairs of matched 4 to 14 years old cases and controls in five French metropolitan areas between 1998 and 2000 - France	Writers code each child's home and school. They point each child's home and school. They calculate a traffic density which they use the formula (I/D: unit = (vehicle/ day)/ m), where I and D were calculated for each home and school. For each address, the index road that was chosen to compute this ratio was the one located in a radius of 300 meters which resulted in the greatest I/D ratio.	Health database (children that had asthma as cases and children without asthma as control group)	No pollution data	Results suggest that traffic-related pollutants might have contributed to the asthma epidemic that has taken place during the past decades among children. Exposure to traffic exhaust during early life is associated with a greater risk of childhood asthma, this association does not hold when exposure is averaged over the life

Table B.5. Literature on the relationship between URD-TRAP and childhood asthma

Study	**Context**	**Characteristic of Urban Environment**	**Detect Asthma**	**Measuring Pollutants**	**Results related to URD**	**Results related to TRAP**
(Ciccone G et al., 1998)	6–7 and 13–14 aged school children (39275 participants) - Italy	*They separate the cities as Metropolitan, Urban or Rural, and Urban *Questionnaire (Questions on traffic included (a) a subjective evaluation of the traffic density in the zone of residence (absent, low, intermediate, high); (b) the frequency of passing buses (0, 1, 2, or more routes) and lorries (never or seldom, sometimes in a day, often in a day) in the street of residence)	Questionnaire	No pollution data	Air pollution from traffic (particularly from heavy vehicles) is potentially hazardous to children's health, increasing the risk for a wide range of adverse respiratory effects, particularly in centers with high levels of urbanization.	Exposure to exhaust from heavy vehicular traffic may have several adverse effects on the respiratory health of children living in metropolitan areas, increasing the occurrence of lower respiratory tract infections early in life and wheezing and bronchitis symptoms at school age.
(Shima et al., 2003)	1858 school children - Japan	*four urban and four rural areas in Chiba prefecture. *Subjects were classified into children who lived <50 m from the edge of trunk roads (roadside area) and children who lived 50+ m from the roads (non-roadside area) (roadside -non-roadside- rural areas)	Four Questionnaires to be able to understand new onset of asthma	Stationary data (NO^2, SO^2, and suspended particulate matter (SPM)	Over the four surveys, the prevalence of asthma was lowest in rural areas among both boys and girls.	The prevalence and incidence of asthma increased among children who lived near trunk roads with heavy traffic. The findings suggest that air pollution primarily derived from automobile exhaust may be particularly important for the

Table B.5 continued

							development of asthma among children living near trunk roads with heavy traffic.
(Hwang et al., 2011)	1819 elementary school students (1005 from metropolitan and 814 from semi-rural) - South Korea	*Seongbuk (metropolitan), Andong (semi-rural) *Questionnaire (Distance between the main road and the house, and the traffic on the road)	ISAAC questionnaire and hospital admission data	Stationary data (SO^2, O^3, NO^2, CO, and PM10)	Although there was no significant difference in the prevalence of self-reported asthma between the two geographic areas (12.8% vs. 13.6%), the prevalence of physician-diagnosed asthma in Andong (15.0%) was significantly higher than that in Seongbuk (6.8%).	No significant difference in the prevalence of asthma in terms of the distance between the main road and the house and the traffic on the road. Because the cities in Korea are very dense, there was no significant difference in the distance between each house and the road, and the traffic and residence area were relatively the same	
(Altug et al., 2014)	16 public primary schools. 605 school children 9 to	*Writers classified the study area into three. Suburban (R1), urban (R2), and urban-traffic (R3) * The total road	interview with the children about their respiratory health	Passive Sampling from schools' playground	Children living in the highest ozone region (suburban, R1) had a	The prevalence of cold in the last seven days were higher in Region 1 and Region 2 (suburban -	

Table B.5 continued

	13 years - Turkey	length within a buffer zone (for 2 km distance) for each school was determined.		(O3, NO^2, SO^2.)	higher prevalence of upper respiratory tract complaints.	urban area) compared to Region 3 (urban-traffic area).
(Alotaibi et al., 2019)	Children <18 years old living in the 48 states and the District of Columbia - USA	*Writers separate the areas as urban and rural *Writers used NO^2, PM10, and PM2.5 data as Traffic-Related Air Pollution (TRAP)	Hospital admission data and survey data	*Stationary data for PM10 and PM2.5. *Estimate NO^2 using land-use regression model (NO^2, PM10, PM2.5)	The percentage of cases due to TRAP was higher in urban areas than in rural areas. TRAP leads to the onset of asthma among children, suggesting that TRAP is responsible for the development of a large portion of preventable childhood asthma in the US. Between 141,900 (18%) and 331,200 (42%) of childhood asthma was attributable to TRAP. The burden of disease varied depending on the pollutant selected in the analysis; results suggest that NO2 contributes to the least disease burden while PM10 contributes to the most.	

Table B.6. Literature on the relationship between URAP and childhood asthma

Study	**Context**	**Characterstic of Urban Environment**	**Detect Asthma**	**Measuring Pollutants**	**Results**
(Corburn et al., 2006)	Asthma hospitalization rates per 1000 persons were calculated for ages 0–14 years for all census tracts for each year from 1997 to 2000 in NYC - USA	Environmental hazard data were obtained from multiple sources and compiled to create a composite area measure called the environmental load profile (ELP). The ELP was generated to estimate harmful respiratory exposures at the neighborhood level. To define ELP, writers used density of air polluting facilities, the density of polluting land uses; manufacturing zone, gas stations, repair garages, power plants, sewage treatment plant, rail yards, truck routes	Hospital databases	No pollution data	Analysis of potentially noxious land uses reveals that these uses tend to cluster in areas with elevated asthma hospitalization rates. Proxy variables, density of stationary source air polluting facilities, polluting land uses, and truck routes for estimating mobile-source air pollution, confirm that the environmental pollution burden in the study neighborhoods is particularly severe as compared to the rest of the city. Neighborhood context does matter for understanding the distribution of childhood asthma hospitalization rates in New York City.
(Rodriguez et al., 2011)	4183 school children in small rural communities undergoing changes related to urbanization in the districts of Eloy Alfaro and San Lorenzo - Ecuador	Writers use some infrastructure, socioeconomic and lifestyle indicators to describe the level of urbanization. The part which we can relate to the urban environment is infrastructure. They use concentration of houses, transport access, presence of health center, pharmacy, secondary schools and	ISAAC-questionnaire	No Pollution data	The study demonstrates that lifestyle indicators and socioeconomic indicators had stronger overall effects on asthma prevalence than infrastructure indicators, indicating that a higher asthma prevalence was present in communities with a higher socioeconomic level and a more urbanized lifestyle. Writers found that asthma prevalence increased with increasing

Table B.6 continued

		uses. (Land-use)			access to electricity, material goods, gas for cooking, and possession of motor vehicles.
(Cavaleiro Rufo et al., 2021)	1050 children at the age of 7 - Portugal	Writers use NDVI (normalized difference vegetation index) and distance to the nearest major road, motorway, or highway	ISAAC-questionnaire	No pollution data	Living surrounded by greener environments was significantly associated with a lower prevalence of asthma and rhinitis at the age of 7. Higher levels of neighborhood greenness at birth (NDVI over 0.14) have a protective effect on the development of allergic diseases and asthma at the age of 7.
(W. Huang et al., 2021)	54,632 pediatric (age ≤18 years) asthma exacerbation cases occurred from 2011 to 2014 - USA	NDVI (normalized difference vegetation index)	Hospital databases	Stationary Data (SO^2, O^3, NO^2, CO, and PM2.5)	Overall greenness (NDVI) was not shown to modify the risk of pediatric asthma exacerbation - one possible explanation could be the generation of aeroallergens (i.e., tree pollens) by certain tree species, which may trigger asthma exacerbation, and writers found that children were more susceptible to air pollution-related asthma exacerbation on days with higher concentrations of grass and/or tree pollens.
(Bobrowska-Korzeniowska et al., 2021)	276 five-year-old children attending randomly selected kindergartens	Urban Heat Islands	ISAAC questionnaire	The GilAir Plus Basic personal sampling (PM10, PM2.5)	No results in the article. The writers explain their project's aim and methodology. But they focus on urban heat islands, which is

Table B.6 continued

	in the urban and rural areas of the Łódź Voivodeship - Poland				essential for neighborhood-level air pollution.
(Paciencia et al., 2022)	6260 children in Porto Metropolitan Area, seven years of age - Portugal	Land Use Mix (LUM) values (1/25000 scale). LUM was calculated within 250 m and 500 m from the child's residence. Writers use four different LUM Indexes	ISAAC questionnaire	No pollution data	Living in neighborhoods with high LUM has a protective effect on current wheezing symptoms. No differences were observed between mean LUM values and clinical diagnosis of asthma, rhinitis, and allergy at seven years of age.

C. Supporting Tables for Methodology

Table C.1. Prediction error values for each Semivariogram type for slope analysis

	Spherical	Circular	Exponential	Gaussian	Linear
ME	-0.0395	-0.0396	-0.0399	-0.0396	-0.0396
RMSE	2.4519	2.4508	2.3860	2.4495	2.4417
SME	-0.0234	-0.0234	-0.0230	-0.0233	-0.0234
RMStdE	1.5605	1.5599	1.4779	1.5567	1.5453
ASE	1.5445	1.5441	1.5835	1.5466	1.5531

Table C.2. Prediction error values for each Semivariogram type for meteorological analysis

	Spherical	Circular	Exponential	Gaussian	Linear
ME	0.0598	0.0574	0.0312	0.0552	-0.0180
RMSE	9.6434	9.6381	9.7192	9.6383	9.8274
SME	0.0058	0.0055	0.0053	0.0054	0.0035
RMStdE	0.9814	0.9808	0.9915	0.9807	1.0067
ASE	9.8662	9.8671	9.8365	9.8680	9.7774

Table C.3. Measurements and traffic data hours in each studied region

	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Thursday	Friday	Saturday	Sunday
	02.11.2021	03.11.2022	04.11.2022	05.11.2023	06.11.2023	07.11.2024	08.11.2021	09.11.2021	11.11.2021	12.11.2021	13.11.2021	14.11.2021
Çankaya Center Region	Measurement hours: 09.13-12.00 Hours of traffic images : 09.15 / 10.15 / 11.15		Measurement hours: 14.29-17.26 Hours of traffic images : 14.30 / 15.30 / 16.30			Measurement hours: 11.13-13.50 Hours of traffic images : 11.15 / 12.15 / 13.15						
Çankaya Periphery Region		Measurement hours: 14.22-17.28 Hours of traffic images : 14.30 / 15.30 / 16.30		Measurement hours: 08.49-11.49 Hours of traffic images : 09.15 / 10.15 /11.15	Measurement hours: 12.12-14.39 Hours of traffic images : 12.30 / 13.30 / 14.30							
Mamak Region							Measurement hours: 09.07-11.15 Hours of traffic images : 09.15 / 10.15 / 11.15			Measurement hours: 14.42-16.43 Hours of traffic images : 14.45 / 15.45 / 16.45	Measurement hours: 12.32-15.00 Hours of traffic images : 12.45 / 13.45 / 14.45	
Sincan Region								Measurement hours: 08.24-10.53 Hours of traffic images : 08.45 / 09.45 / 10.45	Measurement hours: 14.09-16.30 Hours of traffic images : 14.15 / 15.15 /16.15			Measurement hours: 12.24-15.07 Hours of traffic images : 12.45 / 13.45 / 14.45

Table C.4. Road kilometers that have low, medium and high traffic in each region for each hour

		Çankaya Center Region			Çankaya Periphery Region			Mamak Region			Sincan Region		
		low	medium	high	low	medium	high	low	medium	high	low	medium	high
	09:15	17235,61	6258,01	0									
02.11.2021 -	10:15	15859,29	6980,65	0									
Tuesday	11:15	17161,79	8535,71	59,08									
	14:30				19134,61	2609,33	0						
03.11.2021 -	15:30				15729,23	5744,07	0						
Wednesday	16:30				12703,92	9043,38	226,84						
	14:30	16903,89	10829,21	0									
04.11.2021 -	15:30	17814,65	10951,73	192,44									
Thursday	16:30	16536,72	12161,63	1112,89									
	09:15				17036,33	3413,85	0						
05.11.2021 -	10:15				19881,86	847	0						
Friday	11:15				21741,59	1548,96	0						
	12:30				20380,29	951,24	0						
06.11.2021 -	13:30				21206,52	586,55	0						
Saturday	14:30				21096,98	1329,79	0						
	11:15	18004,37	11469,36	0									
07.11.2021 -	12:15	19764,02	11345,86	285,72									
Sunday	13:15	19903,57	12236,07	226,64									
	09:15							3590,84	4659,88	1974,76			
08.11.2021 -	10:15							6543,94	7335,81	152,46			
Monday	11:15							6765,69	8747,6	152,46			
	08:45										9949,95	858,55	0
09.11.2021 -	09:45										11228,34	357,99	0
Tuesday	10:45										12036,65	233,3	0
	14:15										12193,63	472,94	0
11.11.2021 -	15:15										12790,88	1061,27	0
Thursday	16:15										12567,74	984,95	0
	14:45							7472,66	7614,12	1541,26			
12.11.2021 -	15:45							6813,34	9118,85	1724,36			
Friday	16:45							6747,78	9051,64	1724,36			
	12:45							8736,8	7876,36	643,79			
13.11.2021 -	13:45							9344,73	7379,91	1724,36			
Saturday	14:45							11684,69	7412,35	1131,93			
	12:45										10772,08	743,39	0
14.11.2021 -	13:45										11439,81	842,2	0
Sunday	14:45										11364,65	330,42	0
Average		17687,1	10085,36	208,53	18767,93	2897,13	25,204444	7522,274	7688,502	1196,638	11593,75	653,89	0
Buffer Area (km²)		4,93	4,93	4,93	5,65	5,65	5,65	4,32	4,32	4,32	5,54	5,54	5,54
Ratio (m/km²)		3587,647	2045,712	42,29817	3321,757	512,7664	4,4609636	1741,267	1779,746	276,9995	2092,734	118,0307	0

D. Air Quality Measurement Data

Figure D.1. Çankaya Periphery Region Mobile Measurements Field Map

Figure D.2. Çankaya Center Region Mobile Measurements Field Map

Figure D.3. Mamak Region Mobile Measurements Field Map

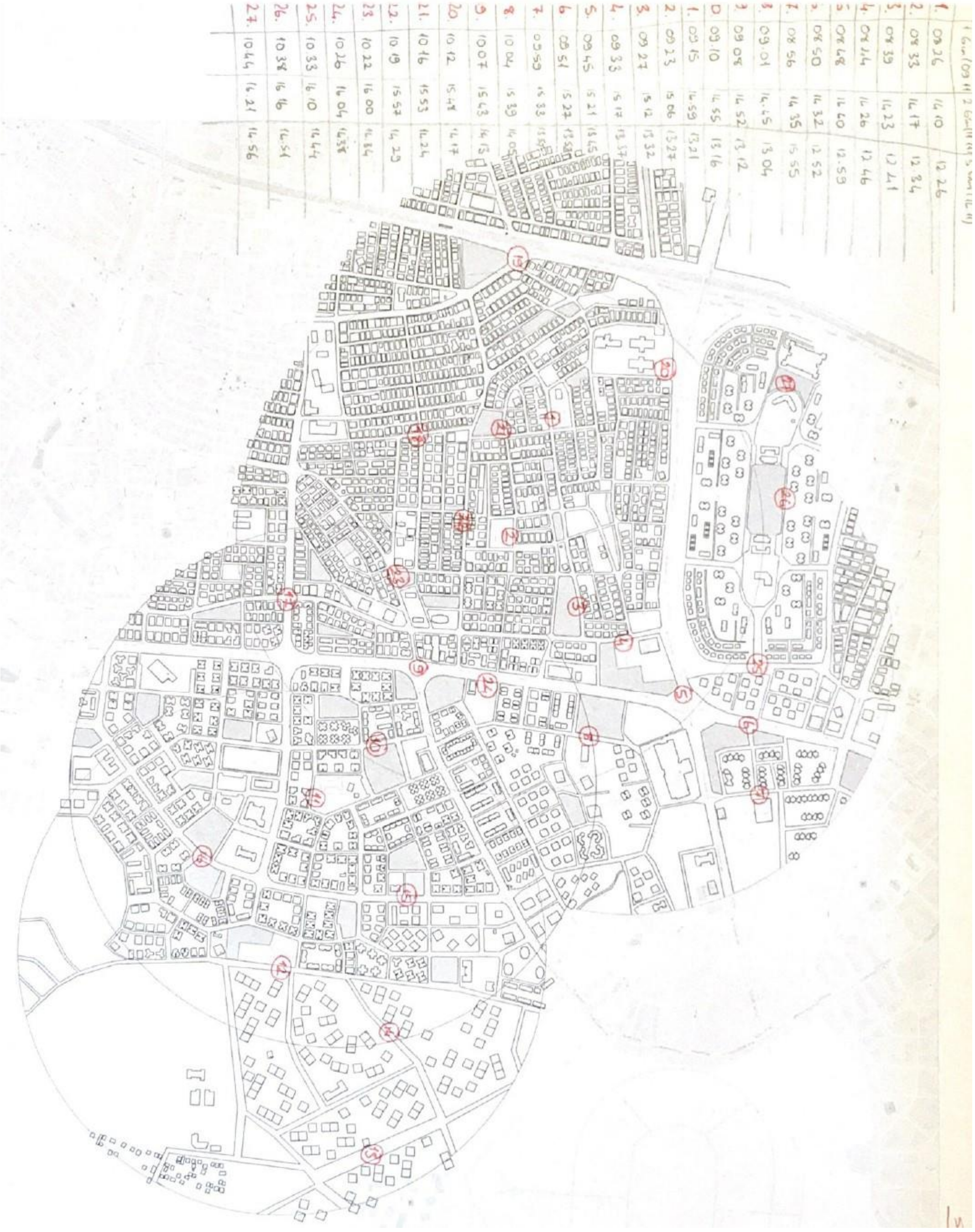

Figure D.4. Sincan Region Mobile Measurements Field Map

Table D.1. Mobile Measurements of the spots in Sincan Region

Sincan (µg/m³)									
ID	time_09_11	PM10_09_11	PM25_09_11	time_11_11	PM10_11_11	PM25_11_11	time_14_11	PM10_14_11	PM25_14_11
S1	08:26	232,60	209,60	14:10	38,00	32,50	12:26	225,60	230,80
S2	08:33	220,40	206,60	14:17	48,00	37,80	12:34	219,00	220,20
S3	08:39	264,00	245,00	14:23	25,50	32,00	12:41	220,75	220,50
S4	08:44	251,33	247,00	14:26	28,20	36,20	12:46	216,20	219,80
S5	08:48	236,00	230,00	14:40	26,75	34,50	12:59	203,25	209,50
S6	08:50	203,20	197,20	14:32	33,00	41,00	12:52	216,00	220,00
S7	08:56	218,00	212,75	14:35	28,50	35,50	15:05	156,66	161,33
S8	09:01	204,00	194,40	14:45	46,16	52,50	13:04	192,40	198,40
S9	09:08	208,00	206,00	14:52	26,50	35,00	13:12	179,00	187,66
S10	09:10	181,00	171,25	14:55	23,33	29,66	13:16	151,25	158,75
S11	09:15	182,60	175,80	14:59	22,33	30,66	13:21	158,40	165,40
S12	09:23	211,66	196,66	15:06	31,40	35,40	13:27	149,25	153,75
S13	09:27	206,40	196,60	15:12	32,25	39,25	13:32	174,50	172,00
S14	09:33	151,80	156,20	15:17	47,00	33,00	13:37	166,00	169,20
S15	09:45	173,80	170,80	15:21	47,80	52,00	13:45	164,60	168,00
S16	09:51	197,40	200,40	15:27	35,20	42,20	13:52	167,50	169,25
S17	09:59	264,25	267,25	15:33	28,80	34,00	13:57	172,40	177,40
S18	10:04	268,00	272,00	15:39	29,33	25,33	14:05	157,20	159,20
S19	10:07	260,00	258,50	15:43	41,75	42,50	14:13	187,33	178,33
S20	10:12	237,00	241,66	15:48	20,00	24,75	14:17	174,00	174,16
S21	10:16	278,50	290,50	15:53	24,66	32,33	14:24	153,50	156,50
S22	10:19	301,50	310,50	15:57	34,50	30,00	14:29	174,50	174,25
S23	10:22	236,33	244,33	16:00	26,66	31,00	14:34	177,33	179,33
S24	10:26	236,40	238,00	16:04	31,40	37,40	14:38	196,20	195,00
S25	10:33	235,40	248,20	16:10	43,40	49,00	14:44	156,40	162,60
S26	10:38	252,80	261,20	16:16	26,75	29,50	14:51	155,25	158,50
S27	10:44	253,00	260,00	16:21	17,87	19,37	14:56	157,00	161,60

Table D.2. Mobile Measurements of the spots in Mamak Region

Mamak (µg/m³)									
ID	time_08_11	PM10_08_11	PM25_08_11	time_12_11	PM10_12_11	PM25_12_11	time_13_11	PM10_13_11	PM25_13_11
M1	09:08	115,50	94,00	14:49	47,60	1,00	12:39	11,00	84,75
M2	09:11	158,00	132,50	14:56	67,66	8,33	12:44	37,75	112,25
M3	09:14	166,00	106,66	15:00	71,00	18,00	12:49	42,20	119,60
M4	09:18	99,66	82,00	15:04	99,25	47,75	12:57	89,00	166,50
M5	09:25	106,66	96,33	15:09	77,00	24,50	13:04	89,40	173,40
M6	09:29	114,50	99,50	15:14	92,50	37,50	13:10	121,00	207,00
M7	09:32	178,00	166,00	15:17	122,00	68,00	13:12	307,33	408,33
M8	09:34	132,20	126,00	15:19	110,00	61,00	13:16	333,50	430,50
M9	09:42	122,00	115,00	15:21	129,00	82,00	13:19	377,66	485,00
M10	09:44	118,00	109,33	15:24	119,20	70,80	13:23	375,20	475,00
M11	09:48	121,66	115,66	15:30	101,60	50,00	13:30	257,20	347,20
M12	09:52	115,50	106,00	15:37	113,66	62,33	13:37	246,25	341,25
M13	09:55	99,00	92,50	15:41	172,20	126,80	13:42	163,75	252,25
M14	09:58	116,00	110,50	15:48	150,66	102,33	13:47	197,33	289,33
M15	10:01	106,66	99,66	15:52	146,00	98,50	13:51	173,75	259,25
M16	10:05	102,00	96,50	15:55	103,66	50,33	13:56	102,00	174,33
M17	10:08	107,50	107,00	15:59	83,50	21,00	14:00	85,00	166,66
M18	10:11	108,00	101,00	16:02	71,00	16,00	14:04	96,00	178,00
M19	10:14	108,00	102,00	16:04	58,00	3,00	14:07	88,66	170,33
M20	10:16	138,50	128,00	16:07	57,00	1,00	14:11	123,66	202,66
M21	10:19	103,00	101,00	16:09	60,66	5,00	14:15	84,66	165,00
M22	10:22	68,66	66,33	16:13	73,50	14,50	14:19	101,33	180,66
M23	10:26	122,40	106,80	16:16	104,50	49,00	14:23	95,33	173,33
M24	10:32	116,20	115,60	16:22	99,50	40,00	14:30	102,80	181,20
M25	10:38	109,00	106,00	16:27	113,00	56,25	14:36	129,33	209,33
M26	10:41	96,50	91,50	16:32	136,00	86,50	14:40	140,50	223,25
M27	10:46	94,33	90,66	16:35	123,66	71,66	14:45	126,60	210,20
M28	10:50	108,00	98,00	16:38	214,00	159,50	14:53	171,00	253,25
M29	10:55	108,00	100,33	16:41	175,00	123,33	14:58	201,33	286,00
M30	10:59	78,40	72,40	15:12	71,00	17,00	13:00	92,33	168,66
M31	11:05	79,66	81,33	14:43	55,00	1,00	12:34	3,75	83,25
M32	11:09	91,00	82,86	16:19	72,50	18,00	14:27	96,00	176,50

Table D.3. Mobile Measurements of the spots in Çankaya Periphery Region

Çankaya Periphery (µg/m³)									
ID	time_03_11	PM10_03_11	PM25_03_11	time_05_11	PM10_05_11	PM25_05_11	time_06_11	PM10_06_11	PM25_06_11
CP1	14:24	49,50	56,75	09:09	153,80	142,40	12:31	181,00	185,22
CP2	14:29	61,00	65,60	11:36	123,33	122,66	14:24	90,00	92,00
CP3	14:35	51,30	56,00	09:19	168,75	151,00	12:41	186,00	188,33
CP4	14:39	47,30	52,00	10:01	142,50	135,00	14:29	114,50	123,25
CP5	14:43	48,30	52,00	10:04	131,33	129,66	13:16	174,00	175,50
CP6	14:47	49,00	54,00	10:11	126,00	126,00	13:14	190,00	186,00
CP7	14:50	54,70	58,50	10:17	123,33	121,33	13:21	132,00	135,50
CP8	14:55	42,40	45,60	10:08	128,50	125,50	13:19	178,00	179,00
CP9	15:01	37,50	40,75	10:21	120,50	120,00	13:24	156,20	157,00
CP10	15:06	48,25	49,25	10:24	121,00	123,00	13:27	151,00	155,00
CP11	15:11	47,00	47,00	10:26	123,00	121,00	13:30	155,00	158,00
CP12	15:16	40,33	42,33	10:28	127,00	125,00	13:31	153,00	159,00
CP13	15:20	43,66	45,33	10:32	123,66	123,00	13:33	157,00	153,50
CP14	15:24	47,25	46,50	10:39	122,00	122,00	13:36	132,00	137,00
CP15	15:29	52,66	53,66	10:30	129,00	125,00	13:32	158,00	159,00
CP16	15:33	47,25	49,50	08:54	125,50	123,50	12:12	197,00	199,00
CP17	15:38	45,75	47,47	10:41	129,50	128,37	13:39	141,66	146,33
CP18	15:43	48,00	48,33	08:59	142,75	138,75	12:17	185,33	191,33
CP19	15:47	62,00	57,25	11:32	123,33	122,66	12:21	186,33	189,66
CP20	15:52	61,50	55,75	11:17	126,40	123,40	14:00	146,66	144,00
CP21	15:57	43,33	45,33	11:23	129,66	126,33	14:04	127,66	131,00
CP22	16:04	47,60	46,80	11:27	130,00	126,50	14:08	121,00	126,00
CP23	16:10	96,25	94,25	11:09	135,66	133,66	14:11	162,50	161,00
CP24	16:15	47,75	51,00	11:13	123,33	119,66	13:52	147,14	149,57
CP25	16:20	48,00	49,75	10:50	134,50	131,50	13:46	143,00	147,60
CP26	16:25	59,00	59,50	09:04	150,00	142,25	12:25	181,00	186,20
CP27	16:34	47,33	48,00	10:57	142,00	141,54	14:14	107,66	111,33
CP28	16:38	71,25	65,75	10:53	141,66	137,66	14:18	111,00	114,00
CP29	16:43	81,33	75,50	09:15	159,00	144,33	14:20	104,66	104,33
CP30	16:50	80,20	73,60	09:24	172,80	149,00	12:45	185,75	185,00
CP31	16:56	65,00	63,66	09:30	134,80	130,80	12:50	196,33	199,66
CP32	16:59	56,75	55,25	09:42	134,80	130,80	12:58	189,60	191,20
CP33	17:04	65,33	61,83	09:53	144,00	144,14	13:11	174,00	177,00
CP34	17:11	53,40	53,20	09:48	130,50	129,00	13:04	181,33	183,00
CP35	17:17	61,28	60,28	09:36	128,60	123,60	12:54	189,00	194,66
CP36	17:27	79,40	76,20	11:46	169,75	167,50	14:33	102,57	109,28

Table D.4. Mobile Measurements of the spots in Çankaya Center Region

Çankaya Center (µg/m³)									
ID	time_02_11	PM10_02_11	PM25_02_11	time_04_11	PM10_04_11	PM25_04_11	time_07_11	PM10_07_11	PM25_07_11
CM1	09:15	34,75	28,75	14:38	75,00	77,00	11:25	96,25	91,00
CM2	09:20	44,00	38,00	14:43	61,66	61,00	11:30	88,66	89,33
CM3	09:23	47,00	42,33	14:47	89,75	91,50	11:35	116,50	119,00
CM4	09:27	51,25	47,00	14:52	84,66	81,33	11:40	113,50	118,50
CM5	09:32	50,50	47,50	14:56	61,00	55,00	11:45	104,00	109,00
CM6	09:37	42,66	42,16	14:41	70,00	71,00	11:21	106,66	102,66
CM7	09:44	33,00	34,00	14:31	75,33	73,33	11:16	94,66	91,50
CM8	09:50	54,54	54,45	15:11	62,66	62,33	11:55	111,00	119,00
CM9	10:02	134,00	93,00	15:18	44,00	38,50	11:58	119,00	119,00
CM10	10:05	92,00	90,00	15:21	57,00	53,25	13:20	56,60	59,60
CM11	10:07	73,50	73,00	15:26	50,66	47,33	13:17	56,00	57,00
CM12	10:10	97,00	98,00	15:30	46,50	44,00	13:14	56,50	58,50
CM13	10:13	80,00	81,00	15:33	48,00	46,00	13:11	46,50	50,50
CM14	10:15	104,00	105,25	15:36	54,50	49,50	13:06	44,50	46,50
CM15	10:20	73,66	73,00	15:41	53,20	47,00	13:03	49,00	53,50
CM16	10:24	76,67	72,66	15:47	108,00	73,00	12:19	107,40	105,00
CM17	10:28	71,75	69,25	16:09	32,00	29,50	12:25	89,00	88,00
CM18	10:33	76,00	72,00	16:12	74,58	63,25	12:27	126,00	105,00
CM19	10:36	134,00	136,50	16:25	85,80	74,20	12:58	46,00	51,00
CM20	10:39	145,40	144,20	16:31	116,00	107,00	12:29	84,33	84,66
CM21	10:45	157,75	158,50	16:33	109,00	102,00	12:33	76,50	76,00
CM22	10:50	145,25	147,00	16:35	94,00	87,50	12:53	54,50	56,75
CM23	10:55	95,50	93,50	16:40	110,40	104,60	12:49	49,25	51,00
CM24	11:00	49,83	47,83	16:46	149,66	141,11	13:00	53,00	54,00
CM25	11:07	38,66	37,00	16:04	39,00	33,00	12:12	102,50	102,50
CM26	11:11	59,25	58,25	16:56	99,50	83,50	12:04	102,57	102,14
CM27	11:16	58,00	58,00	16:59	87,00	80,50	12:01	113,50	116,00
CM28	11:18	46,25	44,75	17:02	79,16	73,66	11:53	63,00	64,00
CM29	11:23	53,50	50,75	14:58	72,00	73,00	11:47	92,00	98,00
CM30	11:28	30,33	27,33	15:04	54,66	46,83	11:51	62,00	67,00
CM31	11:32	46,16	42,66	15:00	37,00	34,33	11:49	79,00	84,00
CM32	11:39	40,28	36,57	17:20	56,00	50,50	13:36	44,66	46,33
CM33	11:47	34,36	31,09	17:23	95,00	84,00	13:40	60,75	63,12

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FOREIGN LANGUAGES

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PUBLICATIONS

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