ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

SPATIAL DISTRIBUTION OF HEALTH RISKS ASSOCIATED WITH $PM_{2.5}$ IN TURKEY AND IRAN USING SATELLITE AND GROUND OBSERVATIONS

M.Sc. THESIS

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Department of Environmental Engineering

Environmental Sciences, Engineering and Management Programme

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

YER VE UYDU ÖLÇÜMLERİ KULLANILARAK BELİRLENEN $PM_{2.5}$ KAYNAKLI SAĞLIK RİSKLERİNİN TÜRKİYE VE İRAN İÇİN ALANSAL DAĞILIMI

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To My Mother Masoume Ghorbankhani, and My Father Nasrollah Samavati.

FOREWORD

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June 2018 Mehrdad Samavati
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ABBREVIATIONS

AOD	: Aerosol Optical Depth
µg/m^3	: Microgram per meter cube
CNG	: Compressed Natural Gas
COPD	: Chronic Obstructive Pulmonary Disease
DoE	: Department of Environment of Iran
GBD	: Global Burden of Disease
GEOS-Chem	: Goddard Earth Observing System chemical
GWR	: Geographically Weighted Regression
IHD	: Ischemic Heart Disease
LC	: Lung Cancer
LIDAR	: Light Detection And Ranging
ML/d	: Million Liter per day
MODIS	: Moderate Resolution Imaging Spectroradiometer
MoEU	: Ministry of Environment and Urbanization of Turkey
MTHM	: Marmara Temiz Hava Merkezi
PM	: Particulate Matter
$PM_{2.5}$	: Particulate Matter with diameter less than 2.5 micrometer
PM_{10}	: Particulate Matter with diameter less than 10 micrometer
RH	: Relative Humidity
SCoIR	: Statistical Center of Iran

SYMBOLS

β	: Exposure-response function
y_o	: Baseline mortality
Pop	: Population
X_0	: Background pollutant concentration

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SPATIAL DISTRIBUTION OF HEALTH RISKS ASSOCIATED WITH PM2.5 POLLUTION IN TURKEY AND IRAN USING SATELLITE AND GROUND OBSERVATIONS

SUMMARY

Industrialization, has been increasing air pollution. In recent decades, the most industrialized and populated cities began to investigate this issue and estimating the cost of health effects for the governments. These researches reasoned the goverments to make new legislation and standards which eventually reduced the air pollution and health effects of it afterward. New York, Paris, London, Seoul and Istanbul are successful examples of this practices.

Iran and Turkey, have almost the same population of 80 million individuals. Such large populations make a high demand in energy production, as some days in winter of 2017, Iran natural gas consumption reached the EU consumption. On the other hand, gasoline consumption in Iran is around 100 ML/d and in Turkey is 68ML/d. Meanwhile, climate change is a serious concern in both countries, which is one of the reasons for dust events in the region.

Ambient PM is the sixth Global Burdon of Disease risk factor responsible for premature death of 4.1M individuals in 2016. Studies on PM health effects, playing the key role in policymaking. To observe and analyze the air pollution trend, ground measurement data is needed. This study, used the very recently published Iran nationwide ground measurements from the years 2015 to 2017.

Since the population in both countries are high and spatially distributed, the number of ground measurement stations are not enough. Thus, spatially more complete remote sensing data was also used in this study. Although PM remote sensing, is still under developments since the instruments only measure AOD and not PM directly. To convert AOD to PM, researchers mostly use GEOS (Goddard Earth Observing System) chemical transport model which first used in 2011 by. For satellite retrievals, dataset V4.GL.02 is chosen in this thesis. This product obtained from three different instruments and with Geos-Chem transport model converted to $PM_{2.5}$. The product has dust and sea-salt removed version which implied to have a better compare with ground measurements, as there are a lot of sand events happening in the region especially in Iran which might mask the anthropogenic sources of $PM_{2.5}$. In addition, dust and sea-salt included version was also used to compare total $PM_{2.5}$ concentrations in both countries.

Initial ground data analysis of Turkey showed that out of 42 available $PM_{2.5}$ stations, 41 stations have reported concentrations above WHO guideline and 45% of stations stand out of European Environment Agency’s standard. Edirne Kesan,

Sakarya Hendek and Erzurum Tashan are the $PM_{2.5}$ stations with annual averages more than 50 mg/m^3 all the time, which is 5 times higher than WHO guidelines.

It was observed that populated cities in both countries such as Ankara, Istanbul, Tehran, Isfahan, Mashhad are experiencing high concentrations due to traffic and domestic energy consumption. Although in cities like Igdir in northeast Turkey, Zabol in southeast Iran or Khuzestan province which are having high concentrations without being populated. The reason for a high $PM_{2.5}$ profile in Khuzestan province

is dust events, as well as in Zabol. Also in southwest Iran is the oil refineries zone of the country, which is responsible for anthropogenic $PM_{2.5}$ emissions mostly.

To calculate the exposure and health effects of $PM_{2.5}$ and PM_{10}, three methodologies exist. The first methodology uses systematic review and meta-analysis oriented exposure-response function, which is based on hundreds of global researches and oriented by meta-analysis. In the second method, AirQ+, a software from WHO can be used to estimate the short-term and long-term adverse health effects of ambient PM. AirQ+ uses life-tables technique and stand on risk estimates oriented from cohort studies. Third method which is mainly used in this thesis is using concentration-response functions from a study in the US and exposure-dose functions to calculate mortality associated with $PM_{2.5}$.

The correlation between $PM_{2.5}$ ground measurements and satellite retrievals was investigated. In general, the correlation was low due to the version of the satellite used for this study which is dust and sea-salt removed, and also the fact that ground stations measure one point and that value is considered as the region/province's average concentration. Therefore when all compositions $PM_{2.5}$ satellite product used, only for this purpose, the correlations improved.

In this study, a high resolution population dataset from European Commission has been used. In order to input this dataset in the function, the resolution reduced to 1000m×1000m to match the $PM_{2.5}$ satellite product resolution.

To estimate the mortality attributable with $PM_{2.5}$, three different causes has been calculated by implying the cause-specific mortality rates for Iran and Turkey from WHO. Firstly, baseline mortality rate for three different causes as: all causes, ischemic heart disease, and lung cancer for Turkey and Iran in 2016 has been calculated. The concentration-response factor for each mortality cause and its upper and lower boundaries, separately obtained from one of the most cited studies in United States. All the datasets such as satellite derived and ground based observations, population, concentration-response factor and baseline mortality rate has been used as inputs for the function which is most commonly used in dose-response and concentration-response estimations. The calculations were performed with ArcGIS spatial analyst tools beside Excel and Google Earth Pro.

The mortality attributable with $PM_{2.5}$, has been calculated based on both ground observations and satellite-derived separately, on district and province level for both countries. In result of satellite-derived based calculations, Istanbul with 6297 deaths, Ankara with 3636 deaths, Izmir with 2254 deaths, Bursa with 1930 deaths, Mersin with 1131 deaths, and Konya with 1116 deaths caused by all causes and attributed to $PM_{2.5}$ in the year 2016. These provinces had the highest mortalities in Turkey. In Iran, Tehran with 6724 deaths, East Azerbaijan with 2587 deaths, Alborz with 2456 deaths, Khuzestan with 2325 deaths, Mazandaran with 2322 deaths and Gilan with 2250 deaths caused by all causes and attributed to $PM_{2.5}$ in the year 2016. These provinces were under the most in Iran. To sum up, 36967 deaths attributable with anthropogenic $PM_{2.5}$ was estimated for Turkey, and 34491 deaths attributable with anthropogenic $PM_{2.5}$ was estimated for Iran in 2016. However, these numbers increase significantly by implying the ground observation $PM_{2.5}$ concentrations. In Turkey, the results based on ground observations were as 10529 deaths in Istanbul, 4094 deaths in Ankara, 2570 deaths in Bursa and 1233 deaths in Erzurum by all causes attributable with $PM_{2.5}$. In Iran though, Tehran with 12383 deaths, Razavi Khorasan with 5376, Khuzestan with 4990 deaths, and Isfahan with 4 601 deaths are the most at risk provinces of Iran.

The other studied mortality cause in this thesis, was ischemic heart diseases. By using the specific concentration-response factors used for ischemic heart disease, and its upper and lower boundaries, mortalities estimated separately based on satellite derived $PM_{2.5}$ and ground observations. By using satellite derived $PM_{2.5}$ in Turkey, Istanbul with 5200 deaths, Ankara with 2893, Izmir with 2893 deaths caused by ischemic heart diseases attributable with $PM_{2.5}$ are the most at risk provinces. In Iran, 5541 deaths, East Azerbaijan 2056 deaths, and in Alborz 2003 deaths have been estimated caused by ischemic heart diseases. As in ground measured $PM_{2.5}$, dust and sea-salt is included, concentrations are higher and thus, estimated mortalities increased. In Turkey, Istanbul with 14165 deaths, Ankara with 5416 deaths, Bursa with 3433 deaths, and Erzurum with 1257 deaths having the most mortalities estimated. In Iran, Tehran with 12383 deaths, Razavi Khorasan with 5376 deaths, and Khuzestan with 1483 deaths estimated as the most at risk provinces. In total, 2817 deaths in Iran estimated with satellite-derived $PM_{2.5}$, caused by ischemic heart diseases attributable with $PM_{2.5}$. In Turkey, 30240 deaths in total have estimated caused by ischemic heart disease attributable with $PM_{2.5}$. By using ground observations, 25525 deaths estimated in Turkey and 3866 deaths in Iran. The ground observation based calculation only contributes to the provinces which $PM_{2.5}$ had been measured in the year 2016.

The third investigated cause, was lung cancer. The reported mortalities by WHO showing higher deaths in Turkey than Iran. Therefore, it affected the baseline mortality rate and estimation's difference of two countries. In Turkey, 5591 deaths in total and 669 deaths in Iran estimated by using satellite-derived $PM_{2.5}$, caused by lung cancer and attributed to $PM_{2.5}$. Although, by using ground measurements total mortality in Turkey changes to 5883 deaths and 776 deaths in Iran.

The calculated results, were relevant to what was reported by State of Global Air. However, results in comparison with the report, results are higher than global reports for Turkey.

Eventually, the risk distribution maps for both countries were produced. Maps were showing central Turkey (Aksaray, Ankara, Konya, Kirsehir) are at high risk, as well as Izmir, Igdir, Mardin, Batman, and Bursa. In Iran, from West Azerbaijan in the northwest, to Tehran in north-center of the country, very high-risk estimations were observed. In south Iran, Khuzestan province observed with high-risk estimations.

YER VE UYDU ÖLÇÜMLERİ KULLANILARAK BELİRLENEN $PM_{2.5}$ KAYNAKLI SAĞLIK RİSKLERİNİN TÜRKİYE VE İRAN İÇİN ALANSAL DAĞILIMI

ÖZET

Sanayileşmenin hava kirliliği üzerindeki olumsuz etkisi her geçen gün etkisini göstermektedir. Son yıllarda, hükumetler için sanayileşmenin ve nüfus yoğunluğunun çok yüksek seviyede olduğu şehirlerde, bu konun araştırılması ve sağlık etkilerinin maliyetinin tahmini daha büyük bir önem kazanmıştır. Daha sonrasında bu araştırmaların sonuçları hükumetlerin hava kirliliğini ve hava kirliğinin insan sağlığına olan etkilerini azaltılması için yeni mevzuatlar geliştirmesine ve standart değerlerin azaltılmasına yardımcı olmaktadır. New York, Paris, Londra, Seul gibi şehirleri bu uygulamaların başarılı örnekleri arasında gösterebiliriz.

İran ve Türkiye'de neredeyse bir birine eş yaklaşık 80 milyonluk nüfusa sahip ülkelerdir. Genellikle bu tür büyük nüfuslar, enerji üretiminde yüksek bir talep oluşturmmaktadır. Buna en iyi örneği 2017 senesinin kış aylarının bazı günlerde İran'ın doğal gaz tüketiminin Avrupa Birliği ülkelerinin toplam tüketim seviyesine ulaşması olarak gösterebiliriz. Diğer taraftan, Türkiye'de günlük benzin tüketimi 68 milyon litreyken İran için bu sayı günlük 100 milyon litre seviyesinde seyretmektedir. Aynı zamanda, iklim değişikliği her iki ülke için ciddi bir endişe kaynağı olup, bu bölgedeki çöl tozu olaylarının ana nedenleri arasında gösterilmektedir.

Dış ortam havasındaki partiküler madde (PM) 2016 yılında 4,1 milyon insanın erken ölümüne sebep olan altıncı yüksek küresel hastalık risk faktörüdür. Bu nedenden partiküler maddelerin insan sağlığı ve çevre üzerindeki etkileri kamu politikalarının geliştirilmesinde kilit rol oynamaktadır. Hava kirliliğinin eğilimini gözlemlemek, analiz etmek ve anlamak için yer ölçüm verilerine ihtiyaç duyulmaktadır. Bu çalışmada son zamanlarda yayımlanan, Türkiye ve İran için 2016 yılı ülke çapındaki yer ölçüm istasyonlarından elde edilen $PM_{2.5}$ verilerini kullanılmıştır.

Her iki ülkedeki nüfus dağılımının genişliği ve gerekli olan yer ölçüm istasyonu sayısının çok fazla olması nedeniyle, bu çalışmada uzaktan algılama verileri de kullanılmıştır. Uzaktan algılama ile partikül madde konsantrasyonlarının belirlenmesi hala gelişme aşmasındadır. Enstrümanlar partiküler maddeyi doğrudan ölçmek yerine Aerosol Optik Derinliği (AOD) parametresini ölçmektedir. Uygun modeller yardımı ile AOD PM'ye dönüştürülmektedir. Bu çalışmada V4.GL.02 uydu verileri kullanılmıştır. İran'da, $PM_{2.5}$'nin antropolojik kaynaklarını gizleyebilecek çok sayıda toz olayı olduğu için, toz ve deniz tuzunun çıkarılmış versiyonunu kullanılmıştır. Bununla birlikte, toz ve deniz tuzunun dahil edilmiş versiyonu da her iki ülkedeki toplam $PM_{2.5}$'i karşılaştırmak için kullanılmıştır.

Türkiye'deki yer ölçümlerinin analizi, mevcut 42 $PM_{2.5}$ istasyonundan 41 istasyonun WHO yönergelerinin üzerinde konsantrasyonlara sahip olduğunu gösterirken, istasyonların 45%'in Avrupa Çevre Ajansının (EPA) standartlarını karşılamadığı gözlemlendi.

Edirne Keşan, Sakarya Hendek ve Erzurum Taşhan istasyonlarında yıllık ortalamalar 50 $\mu g/m^3$'ten fazla olarak WHO yönergelerine göre 5 kat daha fazla $PM_{2.5}$ konsantrasyonları gözlemlendi. Her iki ülkedeki, Ankara, İstanbul, Tahran, İsfahan, Meşhed gibi yüksek nüfuslu şehirlerin trafik ve iç enerji tüketimi nedeniyle yoğunlaşmış $PM_{2.5}$ konsantrasyonuna sahip oldukları gözlemlenmiştir. Bununla

beraber, Türkiye'nin kuzeydoğusundaki Iğdır yada İran'ın güneydoğusundaki Zabol ve Huzistan eyaletlerinde, nüfus kalabalık olamamasına rağmen yüksek konsantrasyonlar gözlemlendi. Huzistan ve Zabol'daki yüksek $PM_{2.5}$ profilinin esas nedenin her iki şehirdeki toz olaylarıdır. Ayrıca, İran'ın güneybatısında , çoğunlukla antropolojik $PM_{2.5}$ emisyonlarının ana sorumlusu olan petrol rafinerilerinin varlığı da bu yüksek emisyon konsantrasyonun nedenleri arasında gösterilebilir.

Bu çalışmada, 2016 senesi için İran ve Türkiyede $PM_{2.5}$ ve PM_{10} maruziyetinin sağlık etkileri hesaplanmıştır. Bu hesaplar üç metodoloji kullanılarak hesaplanabilir. İlk metodoloji yüzlerce küresel araştırmaya dayanan sistematik gözden geçirme ve meta-analize yönelik maruz kalma-tepki fonksiyonu kullanır. İkinci yöntem olan, AirQ+, WHO tarafından geliştirilen bir yazılım olup, dış saha PM'nin kısa ve uzun vadeli olumsuz sağlık etkilerini tahmin etmek için kullanılmaktadır. AirQ+, yaşam tabloları tekniğini kullanır ve kohort çalışmalarından kaynaklanan risk tahminleri üzerinde durur. Bu tezde kullanılan üçüncü yöntem ise, ABD'de yapılan bir çalışmada konsantrasyon-tepki fonksiyonlarını ve $PM_{2.5}$ ile ilişkili ölüm oranını hesaplamak için maruz kalma-doz fonksiyonlarını kullanılmaktır.

$PM_{2.5}$ için yer ölçümleri ve uydu verileri arasındaki korelasyon araştırıldı. Genel olarak, bu çalışmada kullanılan uydu verilerinde toz ve deniz tuzu dahil edilmemesi ve yer istasyonların sadece bir noktada ölçüm yapması sebebiyle korelasyonun düşük olduğu gözlemlendi. Bu sebepten, toz ve deniz tuzu içeren $PM_{2.5}$ verileri ile kıyaslandığında korelasyonlarda iyileşme gözlendi.

Bu çalışmada, Avrupa Komisyonu tarafından hazırlanmış çok yüksek çözünürlüklü bir nüfus veri seti kullanıldı. Bu veri seti çözünürlüğü 1000×1000 m'ye düşürülerek PM uydu verileri ile uyumlu bir çözünülürlüğe getirildi. $PM_{2.5}$ ile ilişkilendirilebilir ölüm oranını tahmin etmek için, İran ve Türkiye için belirli nedenlere bağlı ölüm oranlarını belirtilerek üç farklı neden hesaplanmıştır. Öncelikle, üç farklı neden için taban seviye ölüm oranı hesaplanmıştır. (2016 yılında Türkiye ve İran için tüm nedenler, iskemik kalp hastalığı ve akciğer kanseri). 2009 yılında ABD'de en çok alıntı yapılan çalışmalardan elde edilen her bir ölüm nedenin, üst ve alt sınırları için konsantrasyon-tepki faktörü belirlendi. Uydudan ve yer ölçümleri, nüfus, konsantrasyon-tepki faktörü ve taban seviye ölüm oranı gibi tüm veriler elde edilerek, çoğunlukla doz-cevap ve konsantrasyon-tepki tahminlerinde kullanılan fonksiyon için girdi olarak kullanılmıştır. Hesaplamalar Excel ve Google Earth Pro'nun yanında ArcGIS mekansal analiz araçlarıyla yapıldı.

$PM_{2.5}$'e atfedilen ölüm oranı her iki bölge ve her iki ülke için hesaplandı. 2016 senesinde Türkiye'de $PM_{2.5}$ kaynaklı en yüksek ölüm oranlarına sahip illerin sıralaması 6297 ölümle İstanbul, 3636 ölümle Ankara, 2254 ölümle İzmir, 1930 ölümle Bursa, 1131 ölümle Mersin ve 1116 ölümle Konya şeklinde belirlendi. Aynı yılda İran'da ise $PM_{2.5}$ kaynaklı en yüksek ölüm oranlarına sahip illerin sıralaması 6724 ölümle Tahran, 2587 ölümle Doğu Azerbaycan, 2456 ölümle Alborz, 2325 ölümle Huzestan, 2322 ölümle Mazandaran ve 2250 ölümle Gilan şeklinde belirlendi. Sonuç olarak, 2016 yılında antropolojik kaynaklı $PM_{2.5}$ ‘dan dolayı Türkiye'de 36967 kişi, İran'da ise 34491 erken ölüm hesaplandı. Buna rağmen, bu sayıların zemin ölçümünden elde edilen $PM_{2.5}$ konsantrasyonu verileri dahil edilince önemli şekilde arttığı gözlemlenmiştir. $PM_{2.5}$' için zemin gözlemlerine de dayanan sonuçlar dahil edildiğinde, Türkiye'de İstanbul'da 10529 ölüm, Ankara'da 4094 ölüm, Bursa'da 2570 ölüm ve Erzurum'da 1233 ölüm olayı olmuştur. İran için ise 12383 ölümle Tahran, 5376 ile Razavi Horasan, 4990 ölümle Huzestan ve 4601 ölümle İsfahan en riskli şehirler olarak gösterile bilir.

Bu tez çalışmasında ölüm oranına katkıda bulunan bir diğer faktör ise iskemik kalp hastalığıydı. İskemik kalp hastalığı için kullanılan spesifik konsantrasyon-tepki faktörlerini ve onun alt ve üst sınır ölüm oranlarının tahmini, yer ölçüm istasyonlarından ve uydudan alınan $PM_{2.5}$ konsantrasyon verileri ile belirlendi. Uydudan alınan verilere göre, $PM_{2.5}$ konsantrasyonun neden olduğu iskemik kap hastalıklıları sonucunda Türkiye'de 5200 ölümle İstanbul, 2893 ile Ankara, 2893 ölümle İzmir en çok risk altında olan illerdir. İran'da iskemik kalp hastalığının neden olduğu toplam 5541 ölüm olayından, 2056 ölüm Doğu Azerbaycan'da, 2003 ölüm ise Alborz'da gözlenmiştir. Ölçülen $PM_{2.5}$ seviyesinde olduğu gibi, toz ve deniz tuzu da dahil olmak üzere, konsantrasyonlar daha yüksektir ve bu nedenle tahmini ölüm oranı artmıştır. Türkiye'de 14165 ölümle İstanbul, 5416 ölümle Ankara, 3433 ölümle Bursa ve 1257 ölüm ile Erzurum en çok ölüm olayının gözlemlendiği illerdir. İran'da 12383 ölümle Tahran, 5376 ölümle Razavi Horasan ve 1483 ölümle Huzestan en riskli il olarak tahmin ediliyor. Toplamda, İran'da $PM_{2.5}$'in sebep olduğu iskemik kalp hastalıkları nedeniyle 2817 ölüm olayı uydudan türetilen $PM_{2.5}$ verileri ile hesaplanmıştır. Türkiye'de toplam 30240 ölüm, $PM_{2.5}$'e atfedilen iskemik kalp hastalığından kaynaklanmaktadır. Yer ölçümleri kullanılarak, Türkiye'de tahmin edilen 25525 ölüm ve İran'da 3866 ölüm hesaplanmıştır. Yer ölçümlerine dayalı hesaplama, sadece 2016 yılında $PM_{2.5}$'in ölçüldüğü illere katkıda bulunmaktadır.

İncelenen üçüncü sağlık sorunu akciğer kanseridir. Dünya Sağlık Örgütü tarafından rapor edilen ölüm oranlarına göre Türkiye'de İran'la kıyaslamada çok yüksek ölüm oranı gözlemlenmiştir. Bu durum başlangıç ölüm oranını ve iki ülkenin farklılık tahminini etkilemiştir. $PM_{2.5}$'den kaynaklanan akciğer kanserinden dolayı Türkiye'de toplam 5591 ölüm ve İran'da 669 ölüm, uydudan alınan $PM_{2.5}$ verileri kullanılarak tahmin edilmiştir. Buna rağmen, zemin ölçümleri kullanıldıkta ise toplam ölüm sayısı Türkiye'de 5883 İran'da ise 776 seviyesine kadar değişmektedir.

Üçüncü metotla hesaplanılan ölüm oranı State of Global Air tarafından raporlanan verilerle benzerdir. Buna rağmen, Türkiye için hesaplanan sonuçlar küresel sonuçlardan daha yüksektir.

Sonuç olarak, her iki ülke için risk dağıtım haritaları hazırlandı. Haritalar Türkiye için Aksaray, Ankara, Konya ve Kırşehir'in yüksek risk altında olduğunu, ve İzmir, Iğdır, Mardin, Batman ve Bursa'nın da bunlara yakın değer aldığını gösterdi. İran'da, kuzeybatıdaki Batı Azerbaycan'dan, ülkenin kuzey-merkezinde Tahran'a kadar, çok yüksek riskli bölgeler gözlemlendi. İran'ın güneyinde, Huzeitan eyaletinin yüksek risk değerine sahip olduğu gözlenmiştir.

1. INTRODUCTION

1.1 Background Information

Iran and Turkey both have high concentrations in $PM_{2.5}$, due to the population which is coincidently almost the same. Turkey had some successful practices to decrease the air pollution beginning in the late 90s, and the output was an improvement in air pollution. In Iran also practices continues, but recently as lakes and rivers dries out, new dust point sources being made which alters the air pollution and of course effects the planned practices dramatically.

1.1.1 Study region: Turkey

Like most of developing countries, air quality in Turkey is an important concern. Air quality measurements in Turkey showing most of the cities have concentrations which is considered as harmful to human health by WHO. The concentration of both $PM_{2.5}$ and PM_{10} in Turkey, are much higher than WHO and EPA and EU standards. European Environment Agency (EEA), claims 97.2 percent of the urban population in Turkey is exposed to unhealthy levels of particulate matter (PM10). According to EMEP annual report (M. Gauss, 2016).

Figure 1.1 indicates age-standardized death from $PM_{2.5}$ exposure per a thousand people versus average $PM_{2.5}$ concentration average for the year 2015 by State of Global Air.

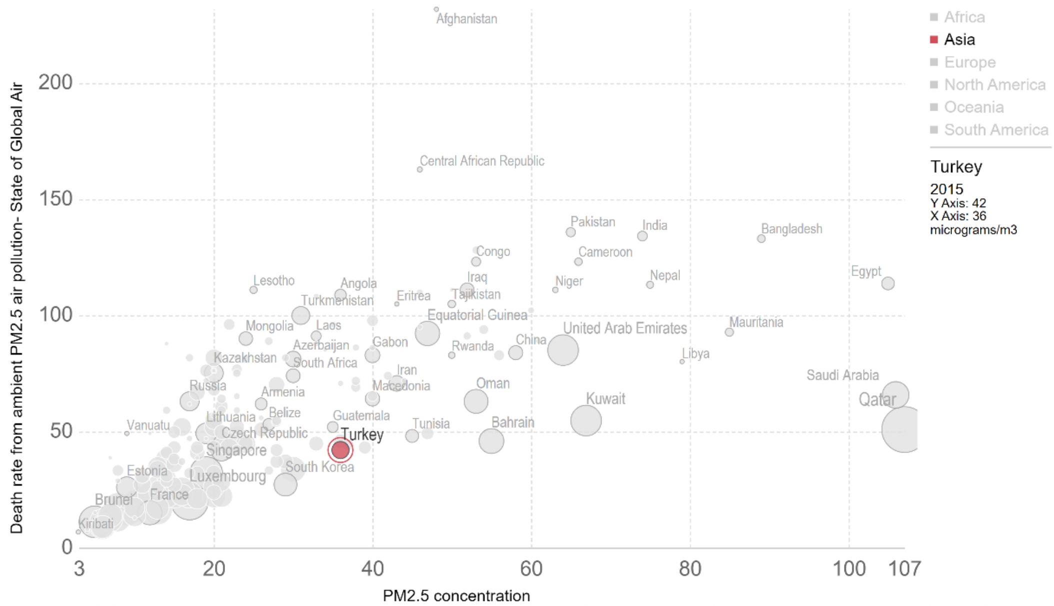

Figure 1.1 : Death rate from $PM_{2.5}$ vs $PM_{2.5}$ concentration in Turkey (2015). adapted from (Air, 2015).

1.1.2 Study region: Iran

The air pollution is the most trending topic among the environmental concerns in Iran, as it even discussed the most in last presidential debates (2017). Iran is an 80million populated country in the middle east, which has suffering environmental crises such as water scarcity and air pollution, and the fourth country to be exposed to drought till 2025 due to the climate change (JahaneSabz, 2018). The natural flow rate of rivers and other water resources has been strongly altered, resulting in ecosystem degradation and lakes drying up such as the Lake Urmia, especially in arid and semi-arid regions (Fazel et al., 2017). Determining whether these effects are because of global warmings or human sources management such as dam construction on the main flows of the region or traditional agriculture. Whatever the reason is, it brought drought to many regions in Iran and its western neighbor Iraq. In result, dust events are getting more and more frequent in the region and it affects southwestern part of Iran, as the concentration of PM recently reached 8600 $\mu g/m^3$ (ISNA, 2018).

Megacities such as Tehran, Isfahan, Mashhad or Shiraz are also suffering high concentrations of PM. The country is a huge consumer of fossil fuels, as average consumes of benzine is more than 78 ml/d and almost the same number for diesel consumption, although the country experiences high consume peak days like 140 ml/d of diesel or 96 ml/d of gasoline (Tribune, Feb 2018). Figure 1.2 shows the mortality estimations by State of Global Air.

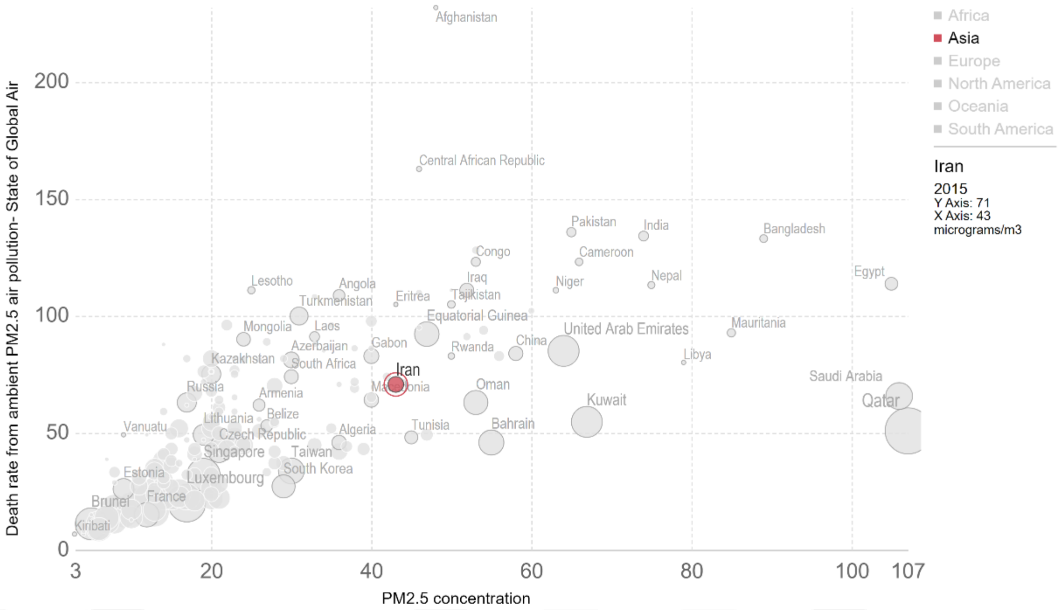

Figure 1.2 : Death rate from $PM_{2.5}$ vs $PM_{2.5}$ concentration in Iran (2015). adapted from (Air, 2015).

1.2 Particulate Matter

Particulate matter or PM which also knows as particle pollution is a complex and geographical based mixture of solid, liquid or solid and liquid particles suspended in the air. These particles in air vary in size, composition, and origin. To study these particles, they needed to be categorized by their aerodynamic properties. Particulate material's aerodynamic controls their transportation and the process of removal of particles from the air. This also affects their deposition within the respiratory system. Particles composition and sources also vary proportionally with these properties. These properties are efficiently compiled by the aerodynamic diameter, that is the size of a unit-density sphere with almost the same aerodynamic characteristics (WHO, 2003). Thus, particulate matters classify in two groups of aerosols with less than 10μm, and 2.5μm.

Exposuring PMs, with different potential, cause health effects. However, current air quality standards are based on total mass of suspended particles (μg/m^3) and do not weight differently to constituents of ambient PM. Current PM studies, mostly focus on $PM_{2.5}$ as its higher health risk (mostly respiratory and cardiovascular disease), due to the majority of anthropogenic emissions fit into this classify (Amato et al., 2015; Ito et al., 2006; Viana et al., 2006). However, this does not mean that the coarse fraction of PM_{10} has no health effect, as concluded by the WHO experts (WHO, 2003).

PM is a chemically non-specific pollutant, and its originate or be derived from various emission source types. Particles generated from a range of stationary and mobile sources and may be directly emitted which is known as primary emissions or generated in the atmosphere which is known as secondary emissions by transformation of gaseous emissions.

1.3 Air Pollution and Health Effects

The study of air pollution naturally began with increased mortality in which the adverse health effects of air pollution was unignorable. The period in the Meuse Valley in 1930, in the small town of Donora in Pennsylvania in 1948. Over five days, nearly half of the town's 14,000 residents experienced severe respiratory or cardiovascular problems. The most flashing episode of December 1952 in London, made the scientists and politicians focus on air pollution health effects studies. The very first model established in 1965 by Holland and Reid which opened the way for many future studies, was a cross-sectional comparison of lung function of postal workers in London compared with that of others in other cities which known as lower polluted or clean air cities. As more countries became industrialized and developed in the 1970s, the adverse health effects became more regarded.

Although the portion of air pollution from combustion of fossil fuel has been lowered in concentrations than 50 years ago, other components have become important. Air pollutions such as photochemical, characterized by high concentrations of Ozone during high-temperature days, has been occurred in places such as Los Angeles or Mexico City, and many cities of Europe. Oxides of nitrogen are the other component which has been produced by vehicles engine. Global warming, on the other hand, caused droughts and so on dust events which changes the airborne particle's size distribution and their toxicity as well.

1.3.1 PM and Cardiovascular Health Effects

PM was often implicated as the most significant predictor of the health outcomes among the air pollutants in recent studies. Many advanced studies prove that PM has significant effects on the cardiovascular system (Dockery et al., 1993). Research on this topic has focused on both the long-term effects of chronic PM exposure and the acute effects of increases in the ambient PM on cardiovascular mortality. In a previous analysis(Brook et al., 2010), it was concluded that for any increase in mortality caused by PM, more than two-thirds of the effect was for the cardiovascular diseases. Table 1.1 shows the long-term effects of PM on the cardiovascular system, collected from different long-term studies.

Table 1.1 : PM long-term effects on cardiovascular system.

Author	Year	PM	Outcome measure	Effect (95% CI)
Dockery et al.	1993	PM_{10}	All-cause mortality	26% (8-47)
Pope et al.	1995	PM_{10}	All-cause mortality	17% (9-26)
	2002	PM_{10}	Cardiopulmonary mortality	31% (17-46)
Hock et al.	2002	$PM_{2.5}$	Cardiopulmonary mortality	71% (10-167)
Pope et al.	2002	$PM_{2.5}$	Cardiopulmonary mortality	9% (3-6)
Pope et al.	2004	$PM_{2.5}$	Ischemic CVD mortality	18% (14-13)
			CHF,arrhythmia, CP arrest	13% (5-21)
Miller at al.	2007	$PM_{2.5}$	Cardiovascular event	24% (9-41)
			Cardiovascular mortality	74% (25-147)
Torent et al.	2007	$PM_{2.5}$	Cardiovascular mortality	12% (7-19)

1.3.2 PM and Respiratory Health Effects

While most of the studies have focused on cardiovascular diseases caused by PM, many studies evaluated the strong association between PM and respiratory health issues. They evaluated these effects may end up with respiratory symptoms, medication use, lung function, health-care utilization, and mortality. Although in long-term exposure studies, respiratory diseases are limited to lung cancer, therefore in this study lung cancer mortality rate from WHO obtained and processed. Table 1.2

is showing the effects of PM on respiratory mortality researched in different studies.

Table 1.2 : Mortality by respiratory diseases caused by PM (Wu et al., 2017).

Author	Year	PM	Outcome measure	Effect (95% CI)
Zeka et al.	2005	PM_{10}	Respiratory mortality	0.87% (0.38-1.36)
Zanobetti et al.	2009	$PM_{2.5}$	Respiratory mortality	1.68 (1.04-2.33)
Wong et al.	2008	PM_{10}	Respiratory mortality	0.62% (0.22-1.02)
Analitis et al.	2006	PM_{10}	Respiratory mortality	0.58% (0.21-0.95)
Amann and Schopp	2011	$PM_{2.5}$	Lung cancer mortality	1.06-1.14 (0.82-1.69)
Pope et al.	2002	$PM_{2.5}$	Lung cancer mortality	8% (1-16)
Ostro et al.	2006	$PM_{2.5}$	Respiratory mortality	2.2% (0.6-3.9)

1.4 Standards

Countries like Iran or Turkey are considered as under developing countries, which makes these governments establish standards and environmental legislation and keep improving them. WHO organization suggests following concentrations for PM:

Table 1.3 : PM standards given in World Health Organization Guideline.

Pollutant	Averaging Period	Concentration, μg/m^3
$PM_{2.5}$	Annual Average	10
	24-Hour Average	25
PM_{10}	Annual Average	20
	24-Hour Average	50

In Turkey, though the Ministry of Environment and Urban Planning successfully adapted the older version of Europe Union standards (EMEP), still lack standards for $PM_{2.5}$ is a concern.

Table 1.4 : PM standards given by Ministry of Environment and Urban Planning 2017.

Pollutant	Averaging Period	Concentration, μg/m^3
$PM_{2.5}$	Annual Average	-
	24-Hour Average	-
PM_{10}	Annual Average	48
	24-Hour Average	70

In Iran, establishing national environment legislations accelerated in last decade. In 2012 the law deputy of president passed new standards which are adapted from EPA and follows the exact numbers as standards (DOEIR, 2013; EPA, 2013).

Table 1.5 : PM standards given by Department of Environment of Iran.

Pollutant	Averaging Period	Concentration, μg/m^3
$PM_{2.5}$	Annual Average	-
	24-Hour Average	35
PM_{10}	Annual Average	-
	24-Hour Average	150

In Europe, the standards for PM is almost the same since 2008.

Table 1.6 : PM standards given by European Environment Agency.

Pollutant	Averaging Period	Concentration, µg/m^3
$PM_{2.5}$	Annual Average	25
	24-Hour Average	-
	3-year average	20
PM_{10}	Annual Average	40
	24-Hour Average	50

1.5 Ground Measurements

The exposure to $PM_{2.5}$ analysis has traditionally been done by using measurements of a ground monitor to people living within a certain distance of it (e.g., a few kilometers) (Laden et al., 2006) to a few tens of kilometers (Samet et al., 2000).

While the classic measurement method is using at almost all air quality observation sites globally, on-site analysis of aerosol chemical composition is very rare as it requires advanced analytical chemical methods and laboratories.

During 2005 to 2007, air quality monitoring stations found their way in Turkey's 81 cities by the Ministry of Environment and Urbanization. Istanbul Metropolitan Municipality also added 10 stations, 6 stations in Izmir operated by Izmir Metropolitan Municipality, 8 stations in Ankara operated by the Ministry of Health Refik Saydam Hıfzıssıhha Center Directorate and 1 station in Kocaeli Dilovası Organized Industrial Site were installed and Turkey National Air Quality Monitoring Network was constituted. In 2015, the number of air quality monitoring stations belonging National Air Quality Monitoring Network has reached to 229 with installations of 20 stations for Samsun Clean Air Center, 15 stations for Erzurum Clean Air Center and 19 of 39 stations planned to be installed for Izmir Clean Air Center. The network established first in order to measure PM_{10} and SO_2, and now also measuring NO, NO_2, NO_x, CO, O_3, $PM_{2.5}$ (Asar, 2017).

In Iran, measuring the air quality began in Tehran by Japanese company JAIKA in 2008. After increasing the air pollution concentrations and crisis around the country, Department of Environment decided to develop the measuring stations in the nation and reporting them online. The most air pollution events in Iran may be in Khuzestan province, in the south-east of Iran. Dust storms and high PM pollution in this region made the government budget 7.3 million USD on this problem, through a cooperation with Environment Ministry of Japan. They installed a CHM15K ceilometers device which is a more advanced device than LIDAR. This device can differentiate natural and anthropogenic source apportionment by using backscattering and adsorption coefficient method (DOEIR, 2017). This device also used by (MeteoSwiss, 2015) for water vapor profile measuring. The nationwide ground-based measurements began in 2016 and for the first time, this data is given to a research by Department of Environment.

1.6 Satellite Retrievals

Remote sensing of the optical properties of the atmosphere from the ground expanded in the 1950s with global observations of sunphotometry. Modern remote sensing of the sky in relation to aerosols at different heights was promoted through the introduction of ground-based light detection and ranging (LIDAR) in the 1960s (Weitkamp, 2005). It has been decades that satellite retrievals provide data about the trend and magnitude of Aerosols and with help of chemical models, we can assess the magnitude of $PM_{2.5}$ and so on PM10.

To analyze the spatiotemporal dynamics of $PM_{2.5}$ concentrations, satellite retrieval data has to be chosen with respect to our spatial and temporal criteria. Table 1.7 shows the current available instruments to measure PM (AOD).

Table 1.7 : Current available instruments to measure PM (AOD).

Instrument	Platform	Spectral Region	Resolution At nadir km^2
MISR	Terra	Vis - IR	18 × 18
MODIS	Terra	Vis - IR	10 × 10
MODIS	Aqua	Vis - IR	10 × 10
OMI	Aura	UV - Vis	13 × 24

1.7 Aim and Scope

Adverse health effects of the air pollution have been the main driving force to investigate, research, reducing standards, and eventually updating relevant legislation in order to reduce air pollution. Turkey and Iran are two countries with serious concerns on air pollution and drought. These crises have symbiotic effects in human health, as many water flows decreased in both countries due to the climate change and both governments dam constructions, PM is having new sources to be emitted. In Iran, lakes as big as the Lake Urumia, are drying out and becoming the new sources of sea-salt and dust which are considered as PM. In developing countries, air pollution-related health studies help to clarify the importance of monitoring and controlling the sources of pollution.

In this study, a time-series quantitative estimate on $PM_{2.5}$ health effects performed with available ground measurement data, combined with satellites retrievals due to inadequate ground measurement stations, and the large area of both countries. Annual concentrations of both PM_{10} and $PM_{2.5}$ were downloaded from Environmental department of both countries and compared with the satellite retrievals for the years 2010-2017. The satellites product used in this study ,V4.GL.02 (van Donkelaar, 2018) is dust and sea-salt removed version which helps to address the PM2.5 sources to anthropogenic sources and population eventually. By using GPWv4 (Commission, 2015), the very high-resolution population product (250m), a correlation between population and ambient PM discovered. Although some cities such as Igdir in east Turkey or Khuzestan in southwest Iran, reported with high $PM_{2.5}$ concentrations, are not populated cities and sources such as dust events and industries are responsible for $PM_{2.5}$ profiles.

In this study, it is aimed to estimate health effects of exposing PM in premature death and mortality rate. Two methodologies are most common used for such studies. In the first method, numbers of articles have been investigated to imply relevant exposure-response function to both countries. The investigated exposure-response function evaluates the mortality rate caused by 10 mg/m^3 increase in unhealthy concentrations by WHO guidelines. In the second method, AIRQ+ a software from WHO, used to estimates the effect of both short-term and long-term exposure to PM.

To sum up, following tasks has been performed in this thesis:

-Investigating the correlation of remote-sensing AOD data with ground measurements in such large countries,

-Comparison of Iran's initial ground measurement reports with satellite retrievals,

-Estimating premature death rate caused by $PM_{2.5}$,

-Targeting the high-risk population by producing the nationwide risk distribution map,

-Comparison the $PM_{2.5}$ concentrations and mortality rates in both countries.

2. LITERATURE REVIEW

Associations between long-term exposure to PM pollution and mortality have been observed in population-based studies and, more recently, in cohort-based studies. Daily time-series and related studies, natural intervention studies, and cohort studies all support the view that relatively induce and continues health benefits are derived from decreasing air pollution (Pope et al., 2009). The World Health Organization estimates that PM pollution contributes to approximately 800,000 premature deaths per year, ranking it the 13th leading cause of mortality worldwide (Lim et al., 2012).

In 2007, the Women's Health Initiative Study researched a group of 65,000 postmenopausal women with no heart disease background over 6 years (Brook et al., 2010). The researchers showed that long-term PM exposure in this population resulted in a 24% (95% CI, 9–41%) increase in cardiovascular diseases and an astonishing 76% (95% CI, 25–147%) increase in cardiovascular mortality per 10-μg/m^3 increase in $PM_{2.5}$. Although the author also claims those 65000 people may be particularly susceptible to ambient PM exposure.

A global study by (van Donkelaar et al., 2015) improved global exposure estimates of ambient $PM_{2.5}$ mass and trend using $PM_{2.5}$ concentrations gathered from multiple satellite instruments. They combined three satellite-derived $PM_{2.5}$ sources to produce global $PM_{2.5}$ estimates at about 10 km × 10 km from 1998 through 2012. For each source, they transformed total column retrievals of aerosol optical depth to near-ground $PM_{2.5}$ using the GEOS–Chem chemical transport model to evaluate local aerosol optical properties and vertical profiles. These studies have to combine with ground measurements to reduce the error of the AOD to $PM_{2.5}$ process using (GEOS-Chem) chemical transport model. Therefore, they collected 210 global ground-based $PM_{2.5}$ observations from the literature to evaluate the satellite-based estimates with values measured in areas other than North America and Europe.

In result, they estimated that global population-weighted ambient $PM_{2.5}$ concentrations increased 0.55 μg/m3/year from 1998 through 2012. The increasing trend of $PM_{2.5}$ in some developing regions drove this global change, despite decreasing $PM_{2.5}$ in some developed regions. The estimated proportion of the population of East Asia living above the World Health Organization (WHO) of 35 μg/m3 increased which was 51% in 1998–2000 and 70% in 2010–2012. Conversely, the North American extent over the WHO Air Quality Guideline of 10 μg/m3 improves from 62% in 1998–2000 to 19% in 2010–2012. It's crucial to find a strong correlation between the satellite retrieval data and ground observed data in such studies, and they found significant agreement outside North America and Europe (r = 0.81; n = 210; slope = 0.68).

To calculate the health effects of PM in a measured concentration, there's basicly one single methodology which is obtained from dose-response studies. These calculations have been based on Poisson regression model (Greenland, 1995). Sheldon Cohen (Cohen, 2004) for the first time developed a human health function from Poisson regression model which calculates premature death due to air pollution. Later on this function also used by (Anenberg et al., 2010; Lelieveld et al., 2013).

Unfortunately, there is no nationwide study with applying satellite retrievals on PM health effects in neither Turkey nor Iran. In Turkey, (TOSUN, 2017) uses AIRQ+, the software from WHO which calculates the health effects of air pollution by given pollution's concentration data. The results obtained for cities Ankara, Adana, Diyarbakir, Izmir, Marmara, and Samsun. There're other studies limited to a single city such as Istanbul (Çapraz, 2013) or Thrace (Mercan, 2016), but unfortunately, no nation study is available in best my knowledge.

In Iran likewise, there is so many cities specified studies such as Tehran (Kazem Naddafi, 2012) which AIRQ+ software has used for assessments. In Ahvaz, southeast of Iran though, in the city that petrochemical industries and other anthropogenic forms of air pollution happen with dust events with (both national and international sources) at the same time, four seasons of the year, using satellite data retrievals would not help health risk assessments as much as accurate ground observations. (Shahsavani et al., 2012) used an aerosol spectrometer (Grimm Aerosol Technik GmbH, Ainring, Germany) to measure PM_{10}, $PM_{2.5,}$ and PM_1 separately. Calculating different sized PM helped them reaching more accurate burden of diseases results. Total mortality during five months of the study period (April-September) is shown 934 deaths attributed to PM_{10} and 197 deaths attributed to $PM_{2.5}$ (Shahsavani et al., 2012). Meanwhile, (Mostafa Hadei, 2017) again by using AIRQ+ software, made a study in 15 Iranian cities, shows 129 deaths in the year 2016 only by lung cancer disease due to $PM_{2.5}$.

3. METHODOLOGY

Three different datasets had to be inputted, to produce the final health risk distribution map. Datasets divided into three main group of air quality, population and exposure-response datasets.

3.1 Air Quality Datasets

Two different datasets were processed and used in the exposure assessment; satellite-derived $PM_{2.5}$ and ground-based observations.

3.1.1 Ground Observation

In this study, both countries' data obtained from Environmental Department. For Turkey, ground observation data downloaded from National Air Quality Observation Network of Ministry of Environment and Urbanization's website. Data collect by 203 PM_{10} stations and 48 $PM_{2.5}$ stations.

In Iran, nationwide air quality data is recently online for the public, not downloadable though. DOEIR shared the data with this study under the official request of the author. 36 Stations observing $PM_{2.5}$ and 29 PM_{10} stations.

The ground observed dataset used in this research is have been taken from below mentioned sources with specific characteristics.

Table 3.1 : PM ground measurement stations in Iran and Turkey.

Source	Country	Data	Stations	Year
DoE	Iran	$PM_{2.5}$	36	2016-18
DoE	Iran	PM_{10}	29	2016-18
MoEU	Turkey	$PM_{2.5}$	2	2015-18
MoEU	Turkey	PM_{10}	170	2011-18
MTHM	Turkey	$PM_{2.5}$	46	2013-17
MTHM	Turkey	PM_{10}	33	2013-17

These data obtained in hourly average and to process these datasets, some processes had to be done. First, they needed to be annually average, and since the technology of MTHM in measuring PM is newer, many corrections have applied by MTHM dataset on the MoEU dataset.

3.1.2 Satellite Retrievals

Aaron van Donkelaar, Randall V. Martin and their team has been estimating ground-level $PM_{2.5}$ by combining Aerosol Optical Depth (AOD) retrievals from the NASA MODIS, MISR, and SeaWIFS instruments. Besides they use AOD measurements from the AERONET (aerosol robotic network) ground-based sun-photometer to calibrate the satellite retrievals. GEOS-Chem chemical transport model which firstly used in 2004 over US (Liu et al., 2004), simulates AOD to PM and afterward, output will be calibrated to global ground-based measurements of $PM_{2.5}$ using Geographically Weighted Regression (GWR). They also produce datasets with dust and sea salt removed $PM_{2.5}$ (van Donkelaar et al., 2015) (Figure 3.1).

To estimate the anthropogenic portion of PM in our study area which experiences sand events often, and it affects the satellite observations dramatically, dataset V4.GL.02 (van Donkelaar, 2018) is chosen, which is their latest products and also has Dust and Sea-Salt Removed $PM_{2.5}$ used for 2016. The dataset is given in ASCII format, the resolution is 0.01°×0.01°, adjusted with 35% relative humidity (RH).

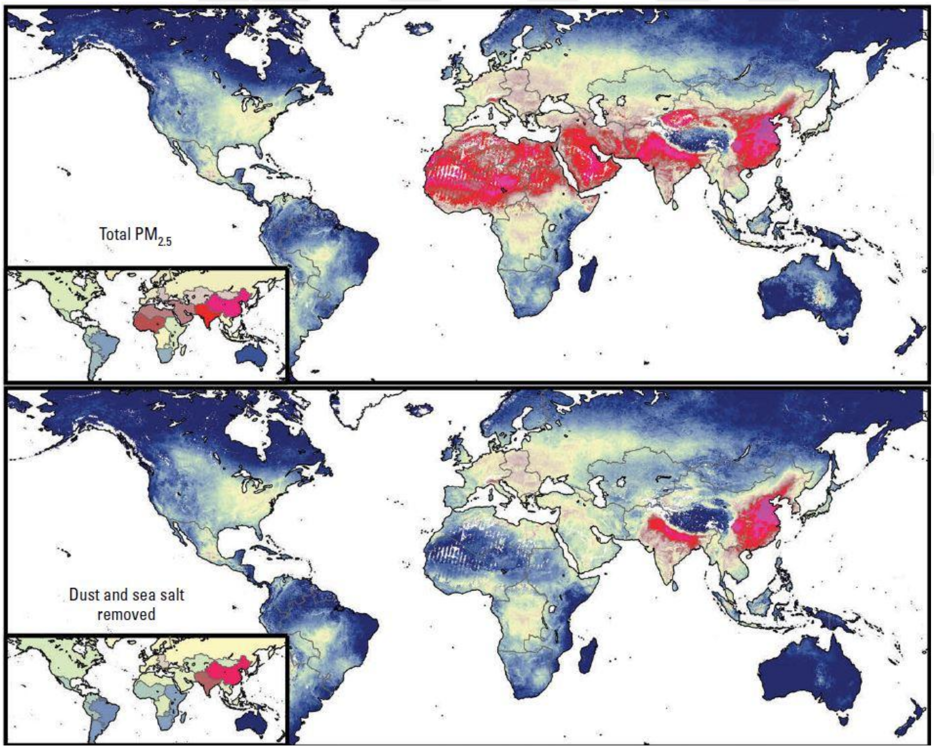

Figure 3.1 : Global decadal average (2001-2010) $PM_{2.5}$ (top shows satellite-derived $PM_{2.5}$, bottom mineral dust and sea salt–free $PM_{2.5}$ (van Donkelaar et al., 2015).

The satellite derived $PM_{2.5}$ with dust and sea-salt for the year 2016 covering Turkey and Iran (Figure 3.2,Figure 3.3) indicated significant contribution in some regions up to 30 µg/m^3 in Iran (Figure 3.4).

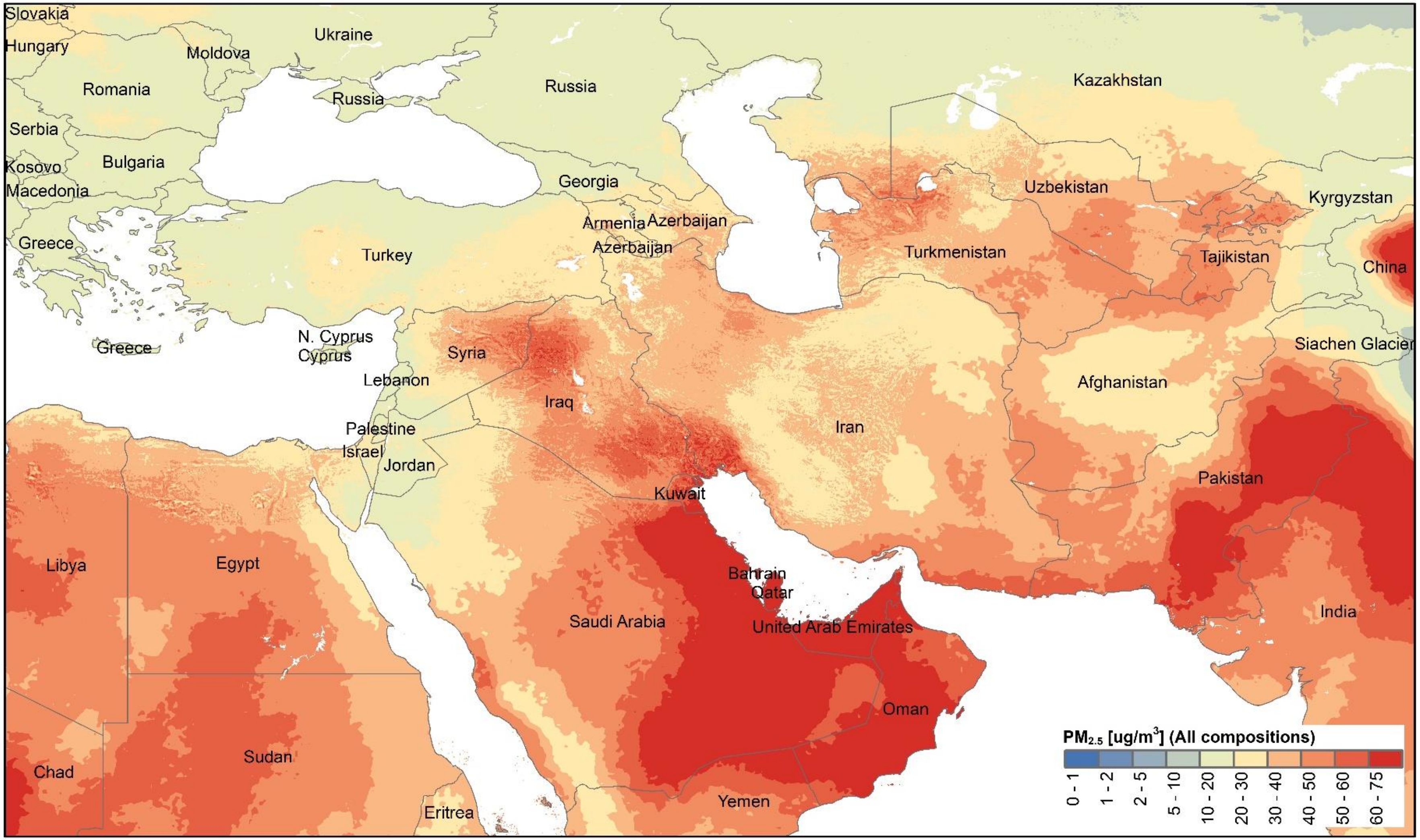

Figure 3.2 : $PM_{2.5}$ concentration of all compositions (dust and sea-salt included) version of satellite derived product in Middle East.

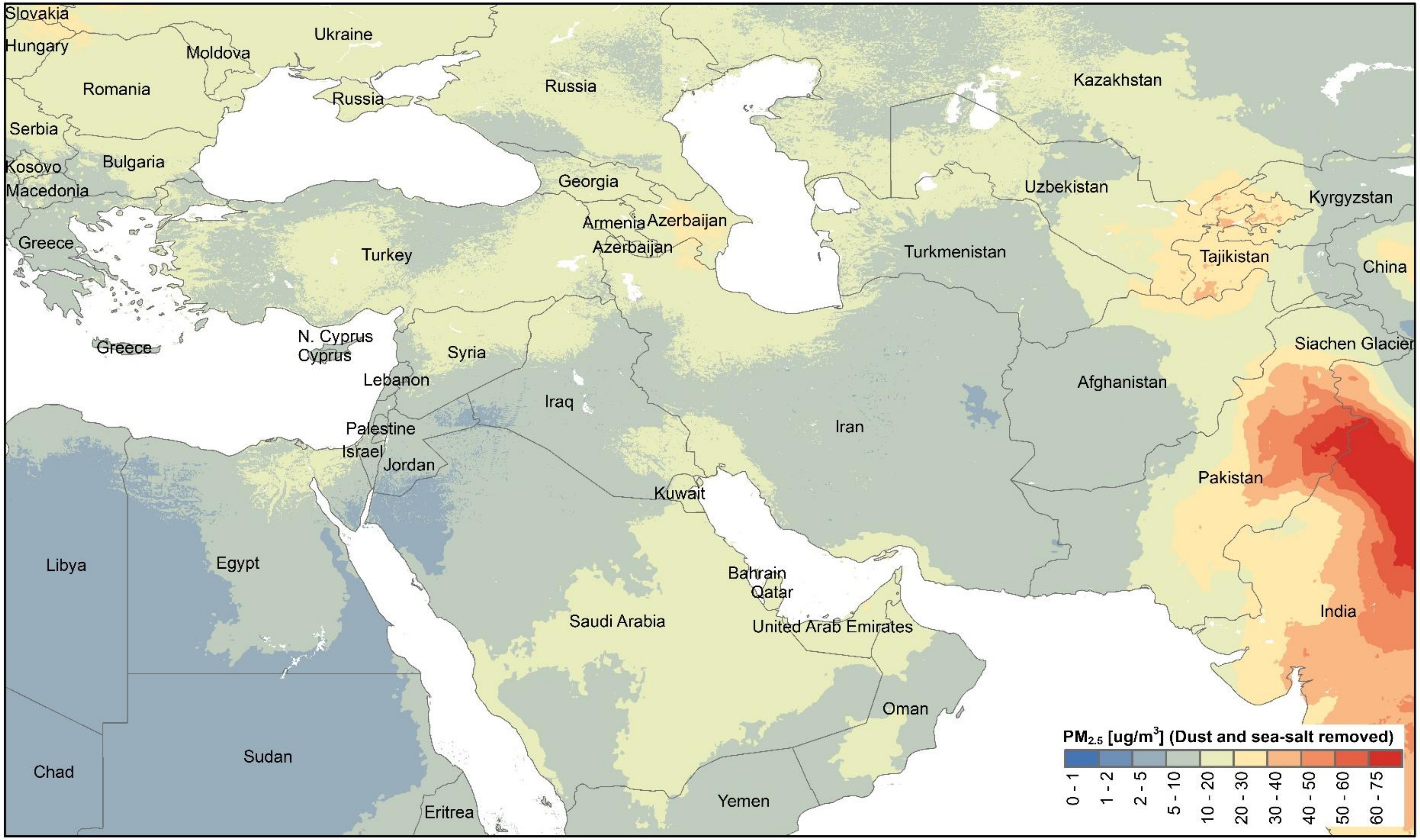

Figure 3.3 : $PM_{2.5}$ concentration of dust and sea-salt removed version of satellite derived product in Middle East.

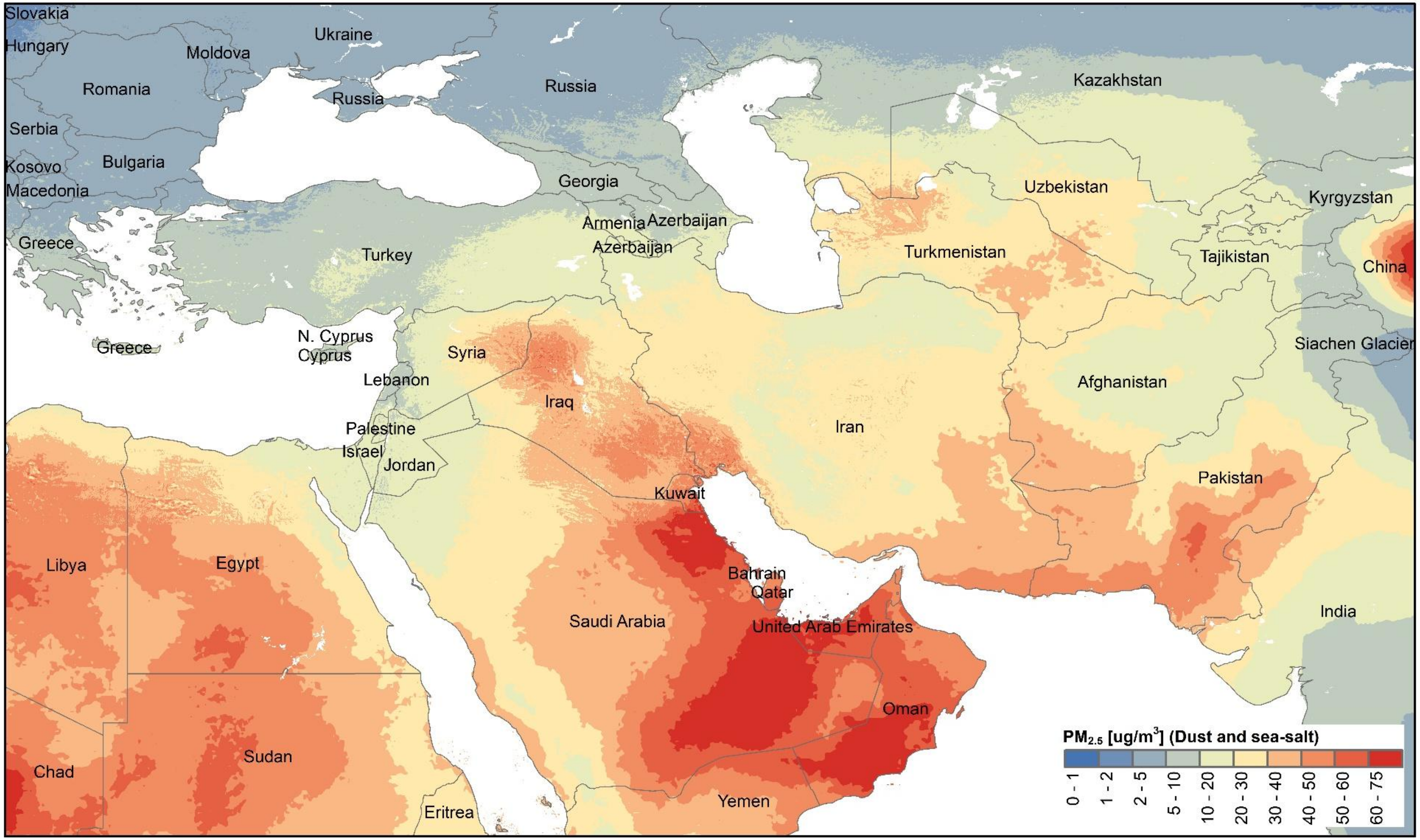

Figure 3.4 : $PM_{2.5}$ concentration of dust and sea-salt from satellite derived product in Middle East.

3.2 Population Dataset

Land use dataset is a necessary tool that should be implied in exposure studies. It provides geographical information on land cover and uses which helps to address the population-based pollutions. The Joint Research Centre European Commission (Commission, 2015) with the contribution of Center for International Earth Science Information Network - CIESIN Columbia University, has provided global land use data with the highest resolution of 250m. In this study, the dataset named GPWv4 is used. This dataset produced by advanced combining global census data and satellite imagery.

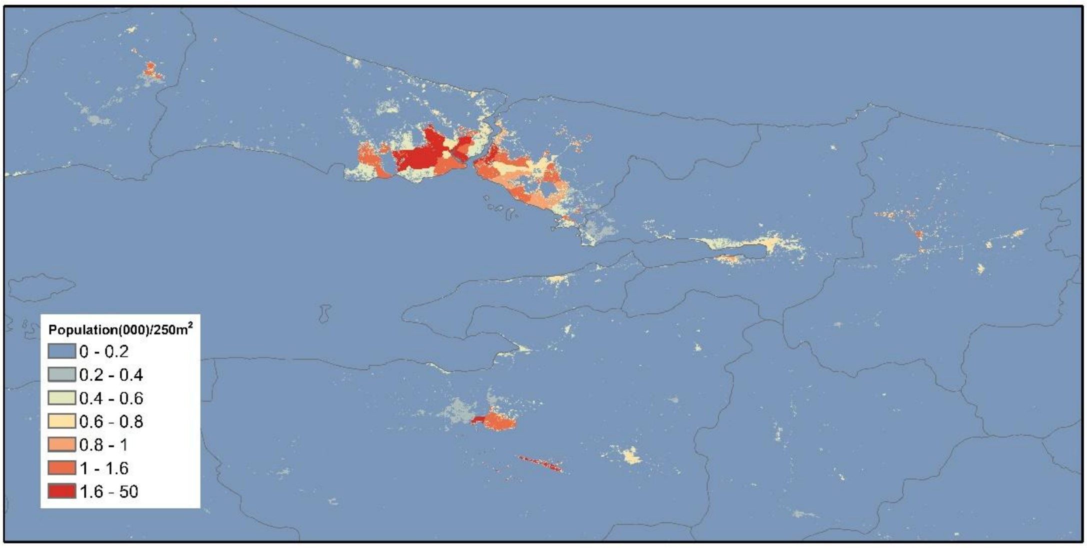

Figure 3.5 : High resolution population spatial distribution from (Commission, 2015) shoeing Istanbul and Bursa's population distribution.

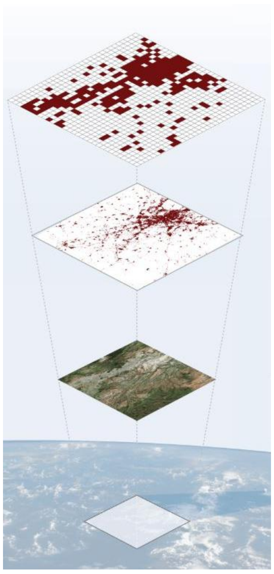

Figure 3.6 : Methodology steps of global human settlement (GHS) dataset production (Commission, 2015).

The population dataset (Commission, 2015), spatially joined with countries boundaries and values in each 250-meter grids, summed up and used in exposure calculations.

Table 3.2 : Top ten most populated cities in Iran and Turkey (Commission, 2015).

Turkey	Population	Iran	Population
Istanbul	14 711 686	Tehran	11 443 539
Ankara	5 278 367	Razavi Khorasan	6 339 710
Izmir	4 070 572	Esfahan	5 318 879
Bursa	3 467 751	Fars	4 802 671
Konya	2 270 401	Khuzestan	4 744 878
Antalya	2 037 731	East Azarbaijan	4 088 807
Gaziantep	2 037 315	Alborz	3 890 951
Sanliurfa	1 806 893	Mazandaran	3 151 406
Mersin	1 765 698	Kerman	3 118 863
Adana	1 699 162	West Azarbaijan	3 105 489

3.3 Health Risk Calculation

Generally, in dose-response health studies, both terms long-term and short-term has been defined. In ambient air pollution studies, most of the researchers are short-term studies, using daily $PM_{2.5}$ concentrations to relate the daily incidence health endpoint associated with $PM_{2.5}$. In this thesis, as there is no available daily hospital admission and death data in both countries, long-term exposure health effects have been researched. The main difference between short and long-term studies are exposure-response functions.

3.3.1 Exposure Calculation

The exposure-response function is to quantitatively measure the mortality rate's change caused by some unit increase in a pollutant's concentration. There have been epidemiologic studies which established the exposure-response function (WHO, 2009). This is a function based on parameters such as age, sex, season, tobacco smoke, education, socio-economy level and pollutant's source-apportionment (Kan et al., 2008). Global studies try to use as much local data as possible to evaluate an exposure-response function. In this study, to best of my knowledge, there hasn't been any epidemiologic study in neither Turkey nor Iran on exposure-response function. Therefore in this thesis, three different exposure-response function obtained from different sources has been used.

The basis of dose-response functions calculation has been based on Poisson regression model (Greenland, 1995). Sheldon Cohen (Cohen, 2004) for the first time developed a human health function from Poisson regression model which calculates premature death due to air pollution. Later on, this function also used by (Anenberg et al., 2010; Lelieveld et al., 2013). The value of health effects (premature deaths caused by $PM_{2.5}$) calculated using .Equation 1.

$$RR = e^{\beta \Delta X} \qquad \text{Equation 2}$$

Where RR is the Relative Risk, β is the exposure-response function, ΔX is the concentration difference between background pollutant concentration (X_0) and observed pollutant concentration. However, the air quality guideline (AQGs) set by the WHO can be also used as X_0 which is based on the impact of a pollutant on human health considering the health assessment reference levels. In this study, it is decided to use the lowest observed concentration in the study area as the reference level (Pope et al., 2002). β is obtained from (Krewski et al., 2009), the epidemiological study in the United States. Due to lack of local cohort studies, it is assumed that the exposure-concentration response factor calculated by epidemiology studies in the United States can be applied for this study.

Table 3.3 : β values used in this study (Krewski et al., 2009).

	Coefficient	Lower Bound	Upper Bound
All causes	0.00554	0.00354	0.00760
Ischemic	0.02167	0.01748	0.02585
Lung cancer	0.01293	0.00554	0.02029

The fraction of the mortality attributable to the risk factor defined as an attributable fraction (AF), showed in Equation 3:

$$AF = 1 - (e^{-\beta \Delta X}) \qquad \text{Equation 3}$$

To calculate the population affected by ambient $PM_{2.5}$,Equation 4 has been used.

$$\Delta Mort = y_0(1 - e^{-\beta \Delta X})Pop \qquad \text{Equation 4}$$

Where Pop is the population affected by the change in $PM_{2.5}$ concentration, y_0 is the baseline mortality rate, and ΔMort is an estimation of the excess mortalities caused by $PM_{2.5}$ exposure. Based on calculated baseline mortality rate from WHO country-specific mortality data, Iran and Turkey have different values. In WHO region divisions, Iran considers as Eastern Mediterian region and Turkey as Europe. The latest estimated death with cause-specific data, downloaded from WHO for the year 2015. Baseline mortality rates for Iran and Turkey were calculated using this data as the ratio of by cause specific mortality over population. Calculated baseline mortality rate for both countries showed in

Table 3.4 and compared with WHO regions in Table 3.5.

Table 3.4 : Mortality and calculated baseline mortality rate for PM pollution specific causes.

Age Range	All Causes		Ischemic Heart Diseases		Lung Cancer	
	Iran	Turkey	Iran	Turkey	Iran	Turkey
30-49	43.6	45.9	7.7	8.6	0.34	3.1
50-59	32.2	34.2	9.4	6.5	0.5	5.6
60-69	45.9	57.1	14.6	12.2	0.7	6.9
+70	163.3	188.9	53.4	46.1	1.6	6.4
Total (≤30)	285.1	326.1	85.2	73.5	3.2	21.9
Baseline Mortality Rate yr^{-1}	0.010696	0.011003	0.003195	0.002481	0.000119	0.000738

Table 3.5 : Baseline mortality 2010 (Lelieveld et al., 2015).

	Eur-B*	Turkey	Emr-B*	Iran
Population**	229	39041	165	38708
All Causes (thousands)	N/A	N/A	N/A	N/A
IHD (thousands)	57	N/A	34	N/A
COPD (thousands)	3	147	N/A	2
LC	7	N/A	1	
Baseline mortality rates*** (yr^{-1})	N/A	0.011003	N/A	0.010696

* WHO mortality stratum of Turkey and Iran are Eur-B (Europe with low child and low adult mortality) and Emr-B (Eastern Mediterranean with low child and low adult mortality), respectively

** ≥ 30 yr, in millions

*** For deaths caused by all causes

3.3.2 Systematic Reviews

Researchers in many countries have done systematic reviews, especially Asian countries which elevated the body of time-series literature since 2004 (HEI, 2004). In systematic reviews, epidemiologic researches have been gathered Table 3.6 and Table 3.7 and filtered by the regions. Then with the help of meta-analysis method, results will be analyzed and relative risk will be obtained

Table 3.6 : An example of a systematic research in China (Wu et al., 2017).

Study city/year	Pollutant	Average PM Concentration (µg/m^3)	Excess Risks (%) of all-cause mortality	95% CI
A district in Shanghai 2002	$PM_{2.5}$	68.0	0.85	(0.32,1.39)
17 Chinese cities	$PM_{2.5}$	87.0	0.40	(0.18,0.61)
17 Chinese cities	PM_{10}	109.0	0.35	(0.13,0.56)
Wuhan 2001-2004	PM_{10}	141.8	0.36	(0.19,0.53)
Shangai 2001-2004	PM_{10}	102.0	0.25	(0.14,0.37)
Hong Kong 1996-2002	PM_{10}	51.6	0.53	(0.29,0.81)
Taiyuan 2004-2005	PM_{10}	155.5	0.25	(0.04,0,46)
Shanghai 2004-2005	$PM_{2.5}$	56.4	0.30	(0.06,0.54)
Gangzhou 2007-2008	$PM_{2.5}$	70.1	0.90	(0.55,1.26)
Xi'an 2004-2008	$PM_{2.5}$	177.0	0.20	(0.07,0.33)
Beijing 2007-2008	$PM_{2.5}$	82.0	0.53	(0.37,0.69)
Shanghai 2004-2008	$PM_{2.5}$	55.0	0.47	(0.22,0.72)
Shenyang 2006-2008	$PM_{2.5}$	94.0	0.35	(0.17,0.53)

3.3.3 AirQ+ From WHO

AirQ+ is a software tool prepared by WHO to estimate the health effects of air pollution. This software measures the health parameters written in Table 3.9. The software's need to input: 1. Air quality datasets, Averaged for long-term and hourly for short-term. 2. Detailed population data, such as group ages to target population at risk 3. Baseline mortality rate, differently for Iran and Turkey. 4. Relative Risk (RR) which is also provided by WHO 5. Population and mortality data.

Detailed population data and mortality data for Turkey downloaded from Turkish Statistical Institue (TUIK, 2018) and (Commission, 2015).

Table 3.7 : Health endpoints outputs by AirQ+.

Health Outcome	Long-term	Short-term	PM
Mortality, all (natural) causes	Available	Available	$PM_{2.5}$
Mortality, ALRI (children 0-4)	Available	N/A	$PM_{2.5}$
Mortality, COPD (adults 30+)	Available	N/A	$PM_{2.5}$
Mortality, IHD (adults 30+)	Available	N/A	$PM_{2.5}$
Mortality, LC (adults 30+)	Available	N/A	$PM_{2.5}$
Mortality, Stroke (adults 30+)	Available	N/A	$PM_{2.5}$
Postneonatal infant mortality, all-cause	Available	N/A	PM_{10}

4. RESULTS AND DISCUSSION

4.1 $PM_{2.5}$ Pollution in Turkey

To process satellite retrievals map, V4.GL.02 product (van Donkelaar, 2018) with (0.01° × 0.01°) resolution, dust and sea-salt removed version used and compared with ground measurements. To calculate the exposure, the population density data GPWv4 (Commission) with 250m resolution has been used to produce population distribution. Ground measurement data downloaded from MoEU, annually averaged and geographically located on the map with ArcGIS program.

To calculate ground measurements dataset and satellite retrievals with population distributions, the datasets had to be in the same resolution. Therefore, satellite dataset with projection feature of ArcGIS projected to km^2, and population dataset with aggregation feature, aggregated to 1 km^2 grids. Then the datasets prepared for exposure-response function and mortality estimation.

To address the anthropogenic sources of $PM_{2.5}$, the correlation between the population and the anthropogenic $PM_{2.5}$ has been calculated. Figure 4.2 shows the population and satellite $PM_{2.5}$ and the correlation between them.

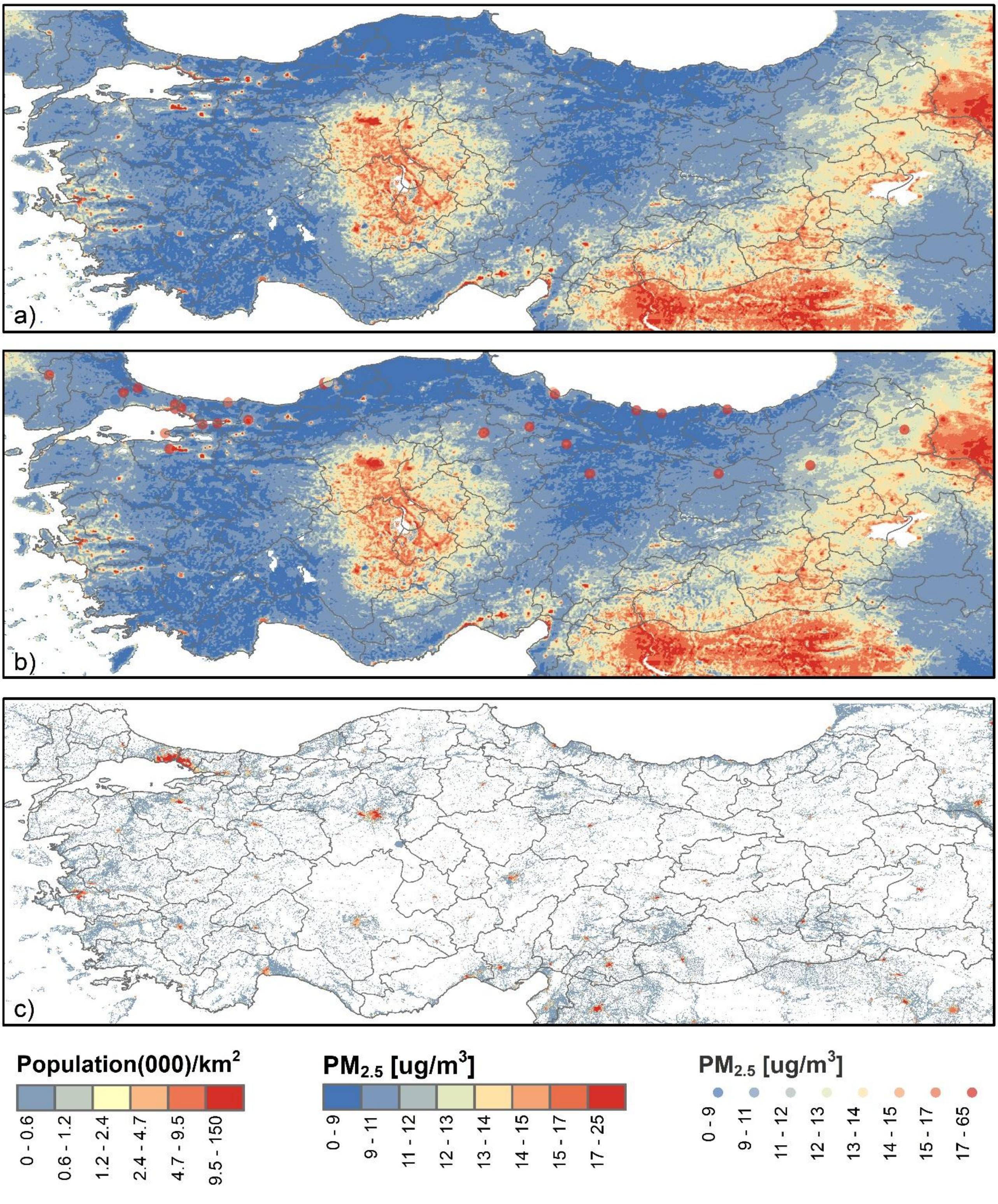

Figure 4.1 : Top panel shows satellite retrievals over Turkey in 2016, Middle panel shows ground station measurements on the satellite retrievals background, Lower panel is the population distribution in 2015.

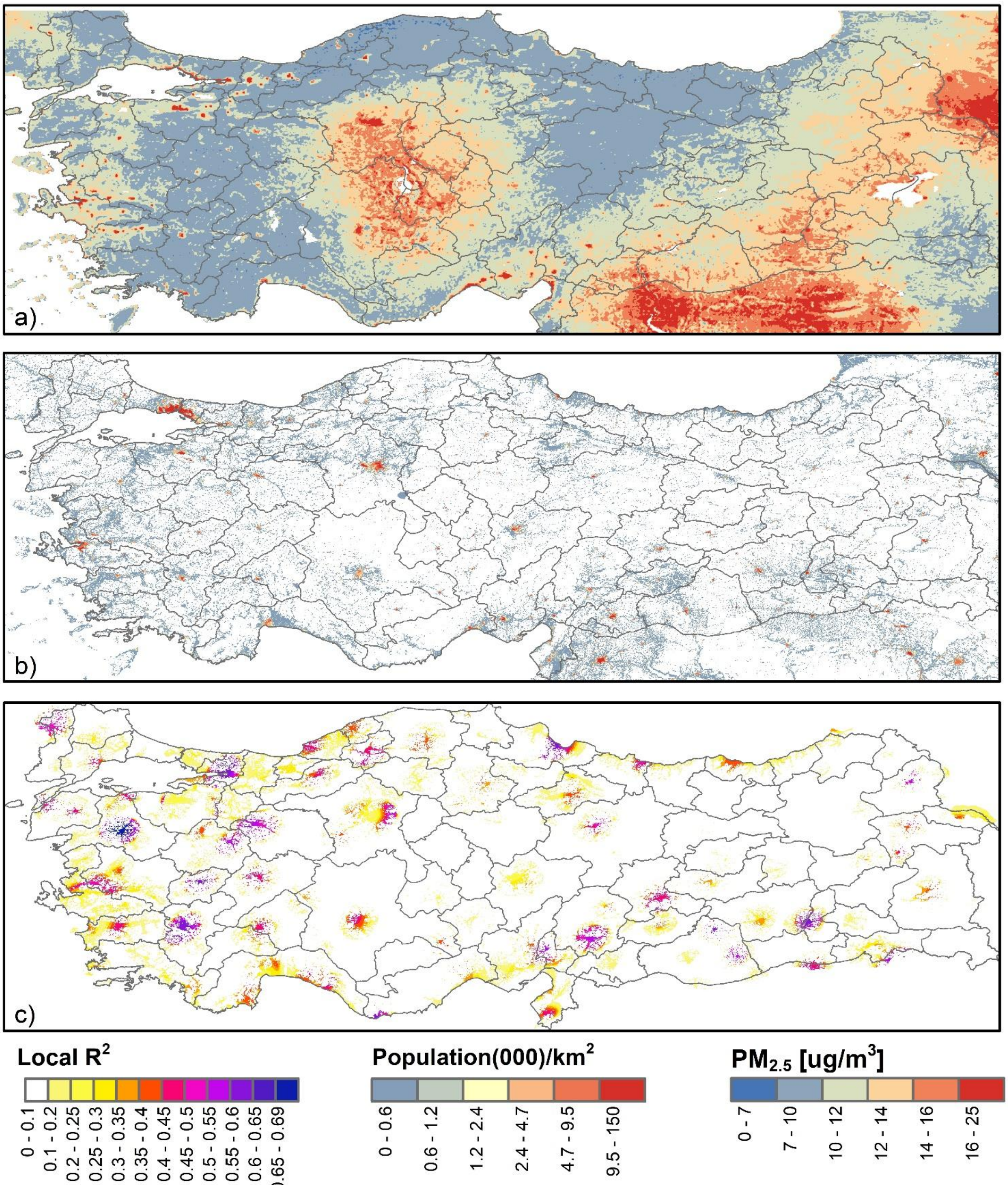

Figure 4.2 : Top panel shows satellite retrievals over Turkey in 2016, Middle panel shows the population distribution in 2015, Lower panel shows the local R^2 between the two upper panels.

4.1.1 Health Risk Estimation using Satellite-Derived $PM_{2.5}$

The evaluation of spatial distribution of health risk attributable with $PM_{2.5}$ was calculated with ArcGIS software, using raster calculator tool. The calculation performed for three different mortality causes, and their range with using three different concentration response factor, average, upper and lower range which is obtained from (Krewski et al., 2009). The other health effects caused by PM is cardiopulmonary diseases which do not include in this thesis, since it is categorized under “other cardiovascular diseases” in WHO mortality data, which consists of other disease codes (ICD-9 401-440 and 460-519) as well as cardiopulmonary and distinguish separate diseases was not possible. To classify the results, quantile feature of ArcGIS is used to have the most representable visual, also zero values to accelerating the calculation converted to null with set to null tool in ArcGIS.

Mortality by all causes

The baseline mortality by all causes calculated by WHO country-specific mortality causes. In this section, the effect of anthropogenic $PM_{2.5}$ in mortality by all causes has been calculated, as it shown in Figure 4.3 to Figure 4.6 for the year of 2016 in Turkey.

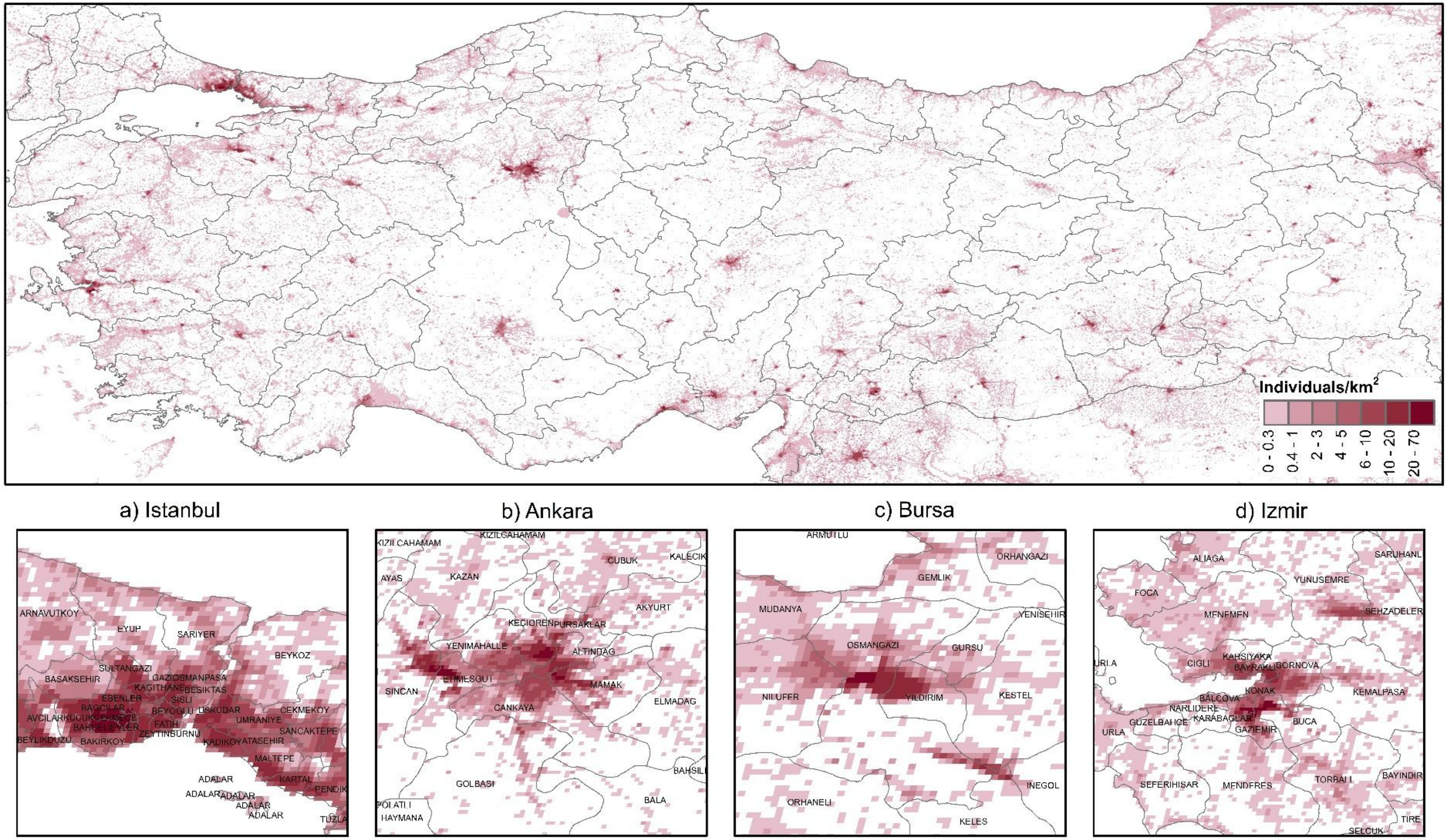

Figure 4.3 : The top panel shows spatial distribution of mortality associated with $PM_{2.5}$ caused by all causes in Turkey. Below panels showing the highest mortality rated cities of Turkey.

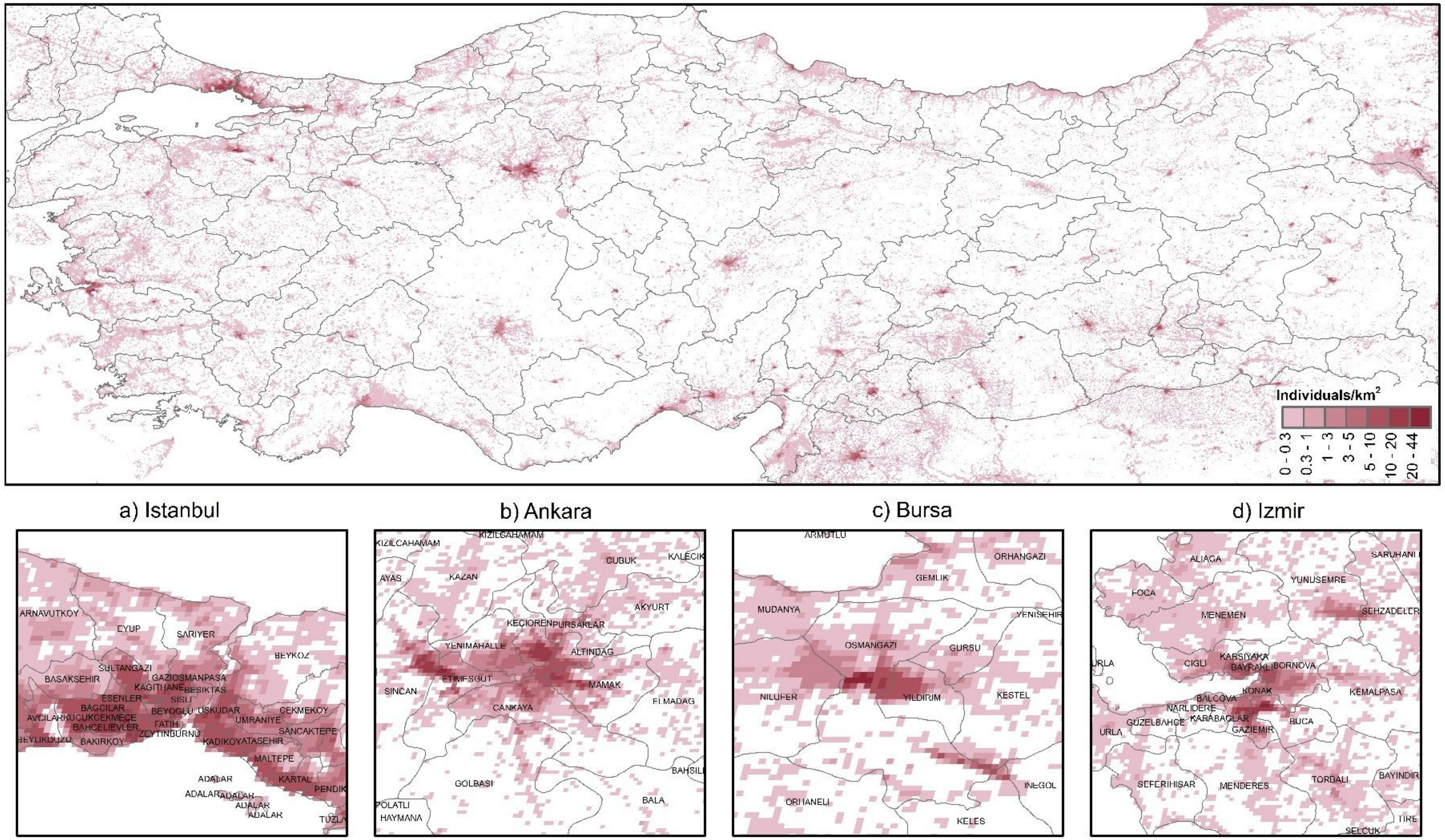

Figure 4.4 : The top panel shows spatial distribution of lower estimated mortality associated with $PM_{2.5}$ caused by all causes in Turkey. Below panels showing the highest mortality rated cities of Turkey.

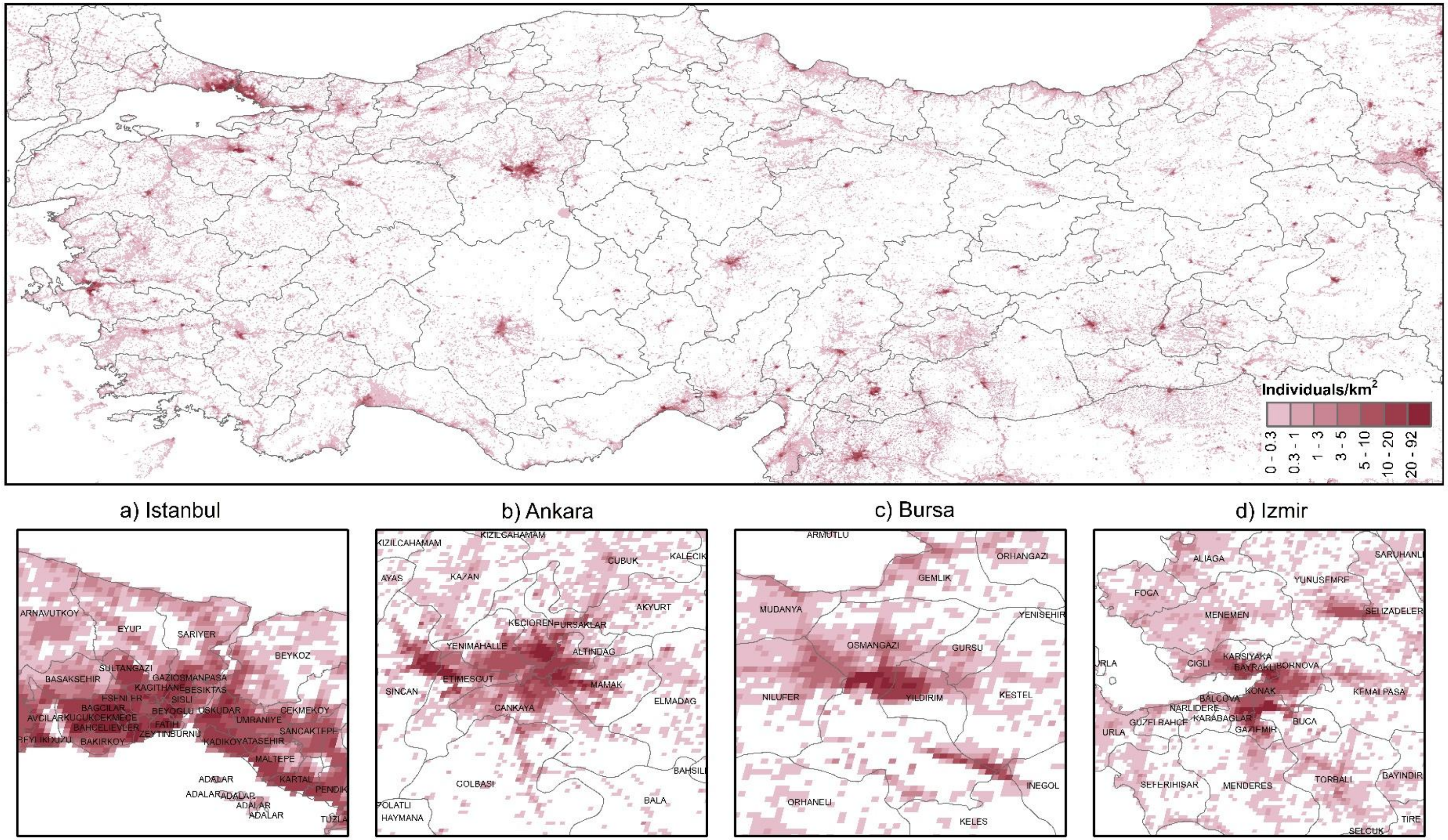

Figure 4.5 : The top panel shows spatial distribution of upper estimated mortality associated with $PM_{2.5}$ caused by all causes in Turkey. Below panels showing the highest mortality rated cities of Turkey.

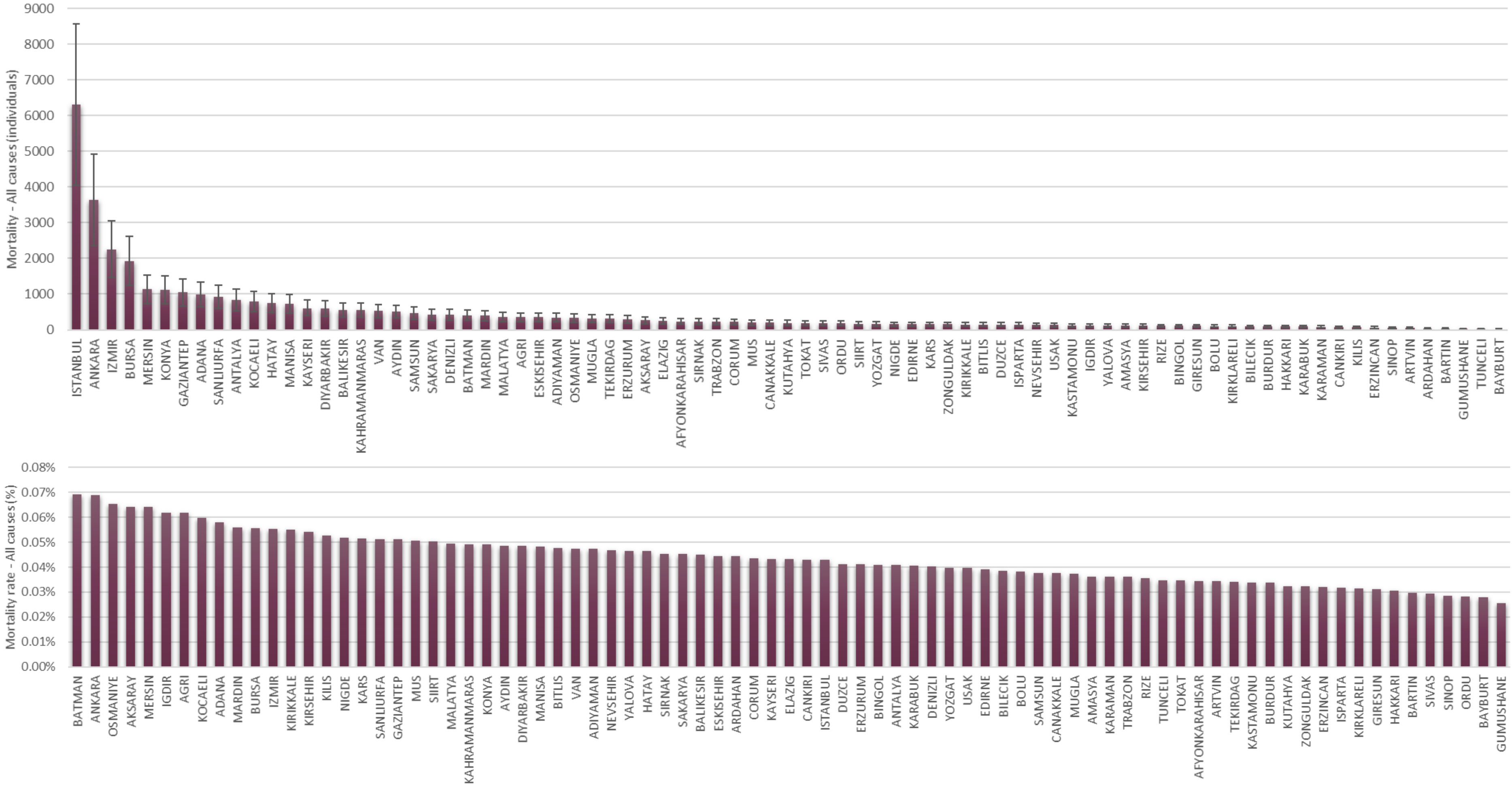

Figure 4.6 : Mortality by all causes associated with satellite-derived $PM_{2.5}$ in Turkey (2016) (upper individuals, below percentage).

As it is ranked in Figure 4.6 the most at-risk population are in Istanbul, Ankara, Izmir and Bursa. Although by considering the population and calculating the percentage of mortality associated with $PM_{2.5}$, ranking changes and Batman, Ankara, Osmaniye, and Aksaray are at most risk, while Istanbul is the 46^{th} rank.

Mortality by Ischemic Heart Diseases

In this set of calculations, deaths caused by IHD investigated and specific concentration-exposure factor and baseline mortality rate for IHD has been used to calculate the mortality caused by IHD associated with anthropogenic $PM_{2.5}$. As it shown in Table 3.3 IHD has higher concentration-response factor than lung cancer, meaning $PM_{2.5}$ has a more adverse effect on IHD than LC.

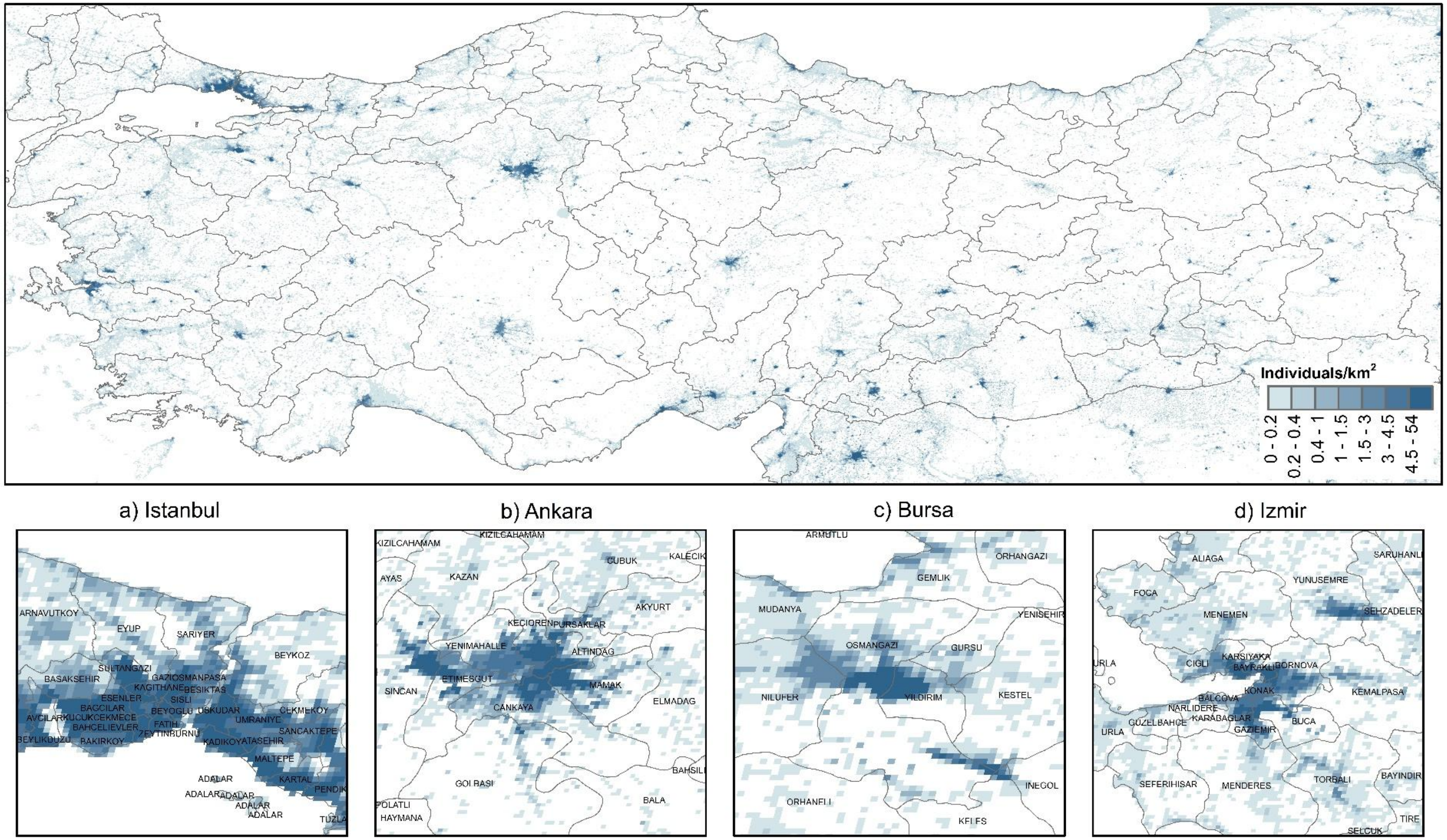

Figure 4.7 : The top panel shows spatial distribution of estimated mortality associated with $PM_{2.5}$ caused by ischemic health diseases in Turkey. Below panels showing the highest mortality rated cities of Turkey.

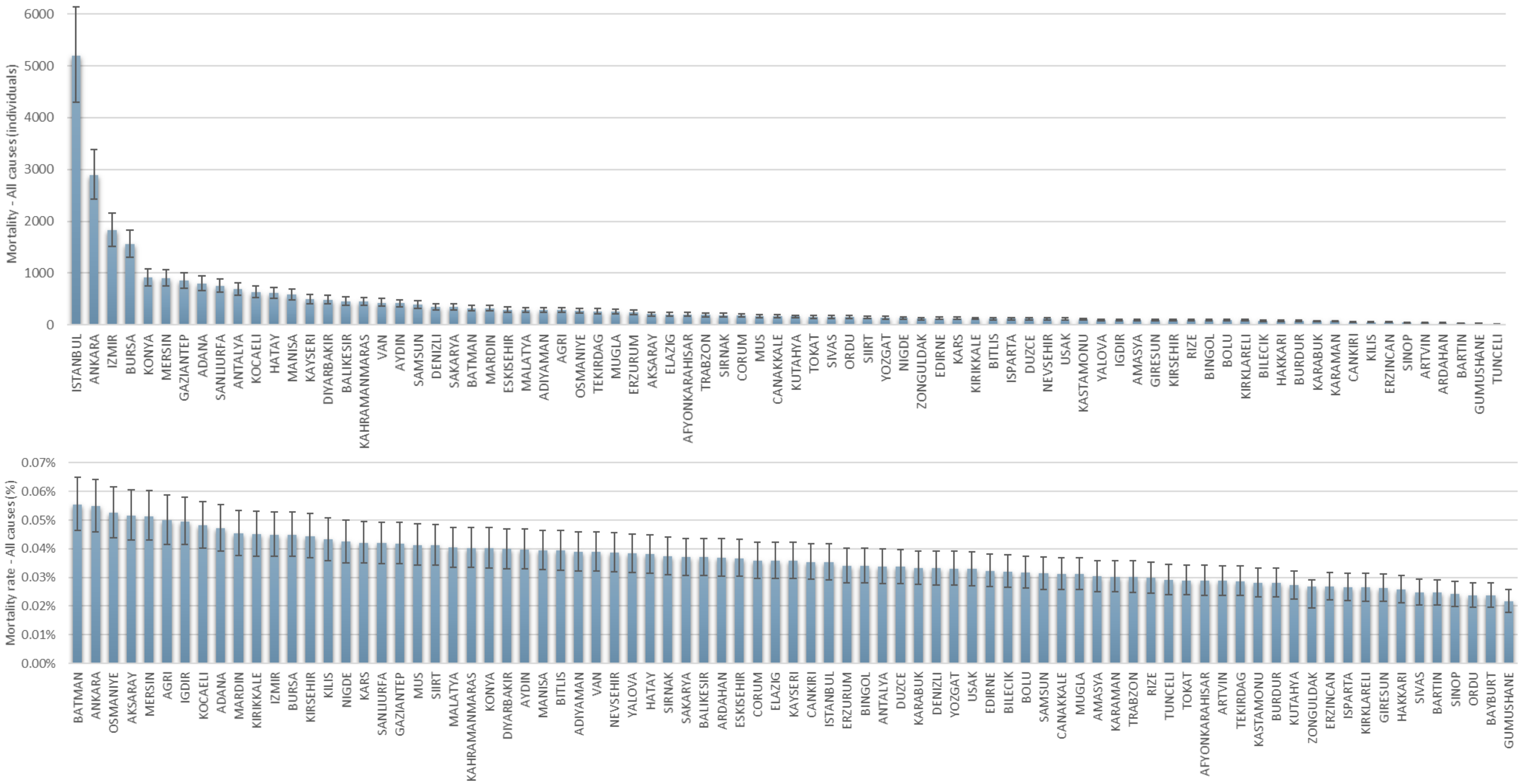

Figure 4.8 : Mortality by Ischemic health diseases associated with satellite-derived $PM_{2.5}$ in Turkey (2016) (upper individuals, below percentage).

Results of the year 2016 showing the death of almost 5200 individuals in Istanbul only, following with Ankara and Izmir. The percentage of mortalities is almost the same with all causes mortality results in top 10 most at-risk cities, although the baseline mortality rate is slightly different. This might be because of the large population in top 10 most at-risk cities, which affects the results significantly.

Mortality by Lung Cancer

The concentration-response coefficient for LC is the lowest coefficient, and this is the only respiratory health effects which are investigated in long-term exposures. In the WHO cause-specific mortality data, LC coded as 162 in ICD-9 classification system.

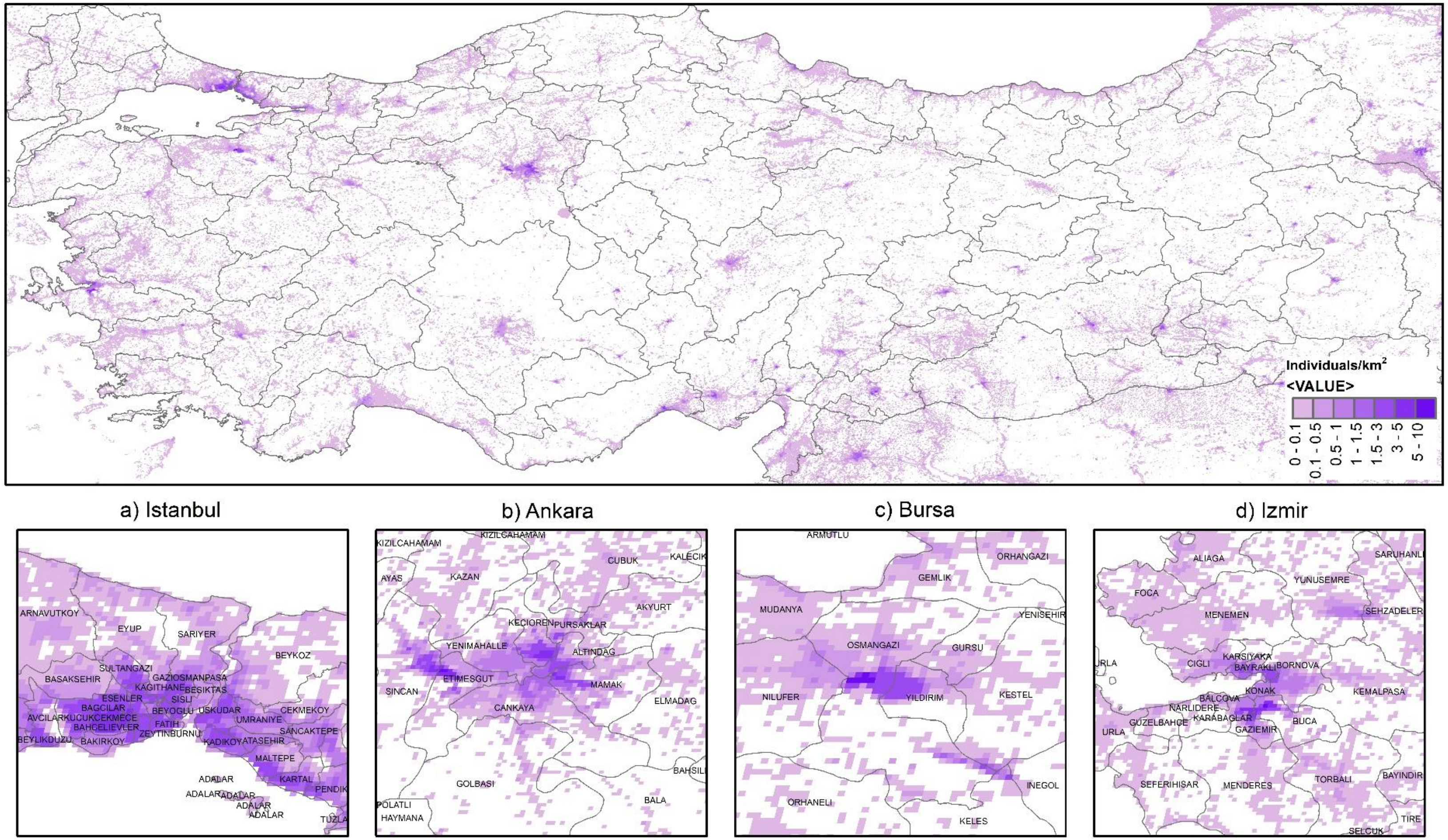

Figure 4.9 : The top panel shows spatial distribution of mortality associated with $PM_{2.5}$ caused by lung cancer in Turkey. Below panels showing the highest mortality rated cities of Turkey.

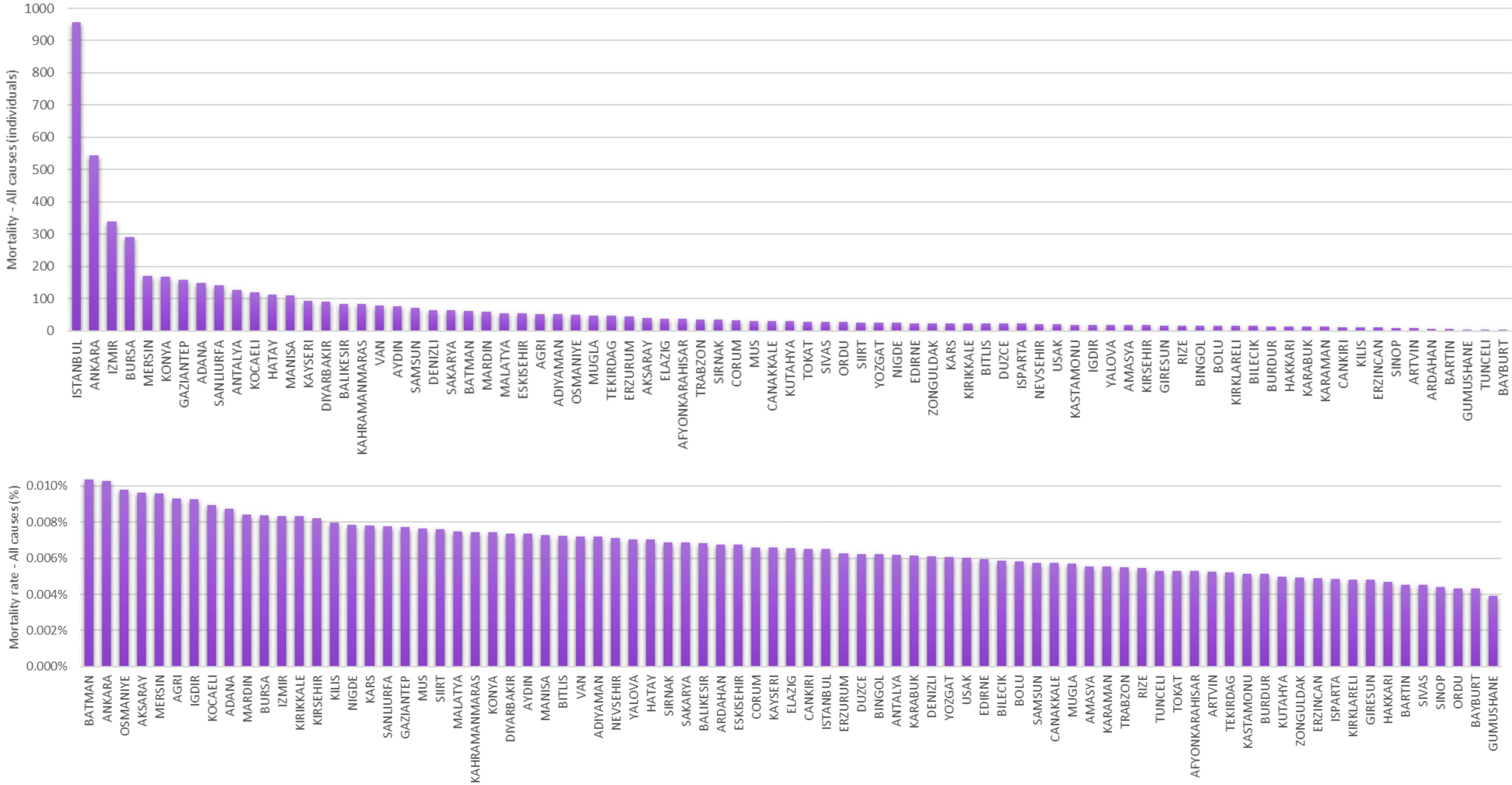

Figure 4.10 : Mortality by lung cancer associated with satellite-derived $PM_{2.5}$ in Turkey (2016) (upper individuals, below percentage).

4.1.2 Health Risk Estimation using Ground-based $PM_{2.5}$

To process the long-term exposure, ground data had to be averaged annually. In the first phase of ground measurement data process, values of provinces averaged and used as the concentration of that province in exposure-response function. This might increase the uncertainty especially in high populated provinces. For instance, in Istanbul, only three stations are measuring $PM_{2.5}$ and their values averaged and used as the concentration that almost 14million people exposure equally, while the concentrations in Sariyer district is supposed to be lower than Fatih district in Istanbul. Since the lowest ground observed concentration is not representing the background $PM_{2.5}$ (X_0) of Turkey (due to lack of nationwide stations), satellite retrieved X_0 has been used for calculation.

The correlation between ground $PM_{2.5}$ measurements and satellite-derived dust and sea-salt removed data shown in Figure 4.11. Although this correlation is higher by excluding two outliner ground measured values.

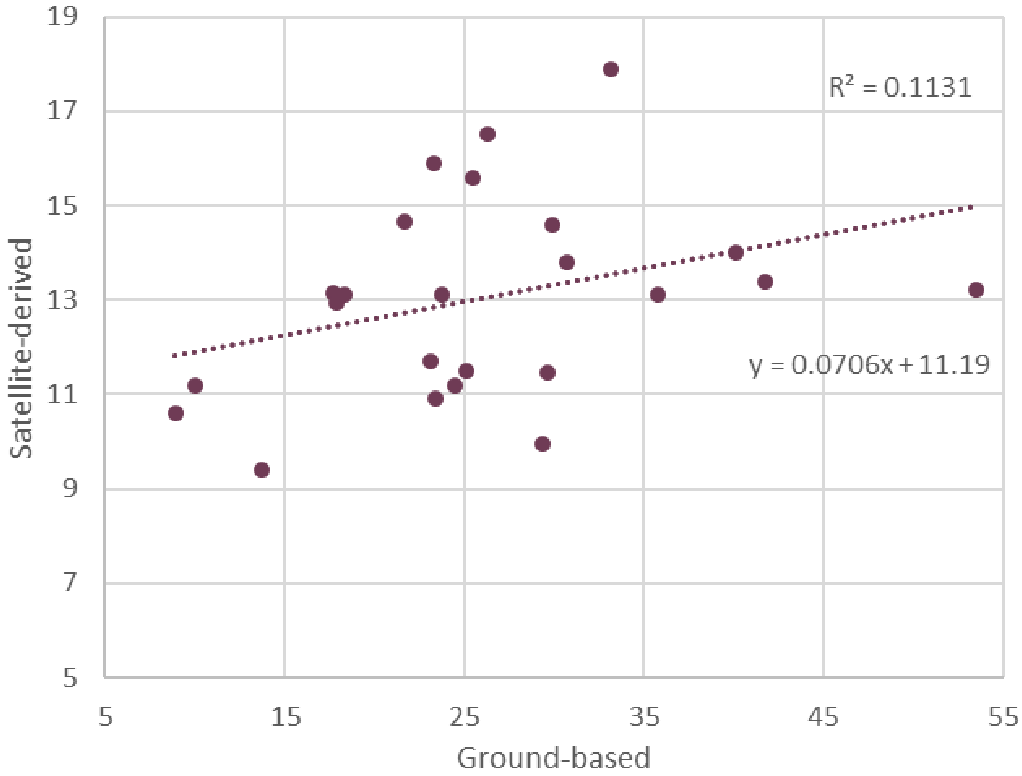

Figure 4.11 : Ground measurement vs Satellite-derived data of Turkey (2016).

Mortality by all causes

In this section 24 reported as measured $PM_{2.5}$ provinces obtained from MoEU, and the effect of all sources $PM_{2.5}$ on mortality has been calculated. The total number of

40583 (26493,54472) individual death are very larger than satellite-derived calculations, especially when it is calculated out of 35024768 living individuals in 24 calculated provinces. The reason for this would be the above mentioned averaging method, and also the lower annual concentration of $PM_{2.5}$ satellite product due to filtering dust and sea salt from the product.

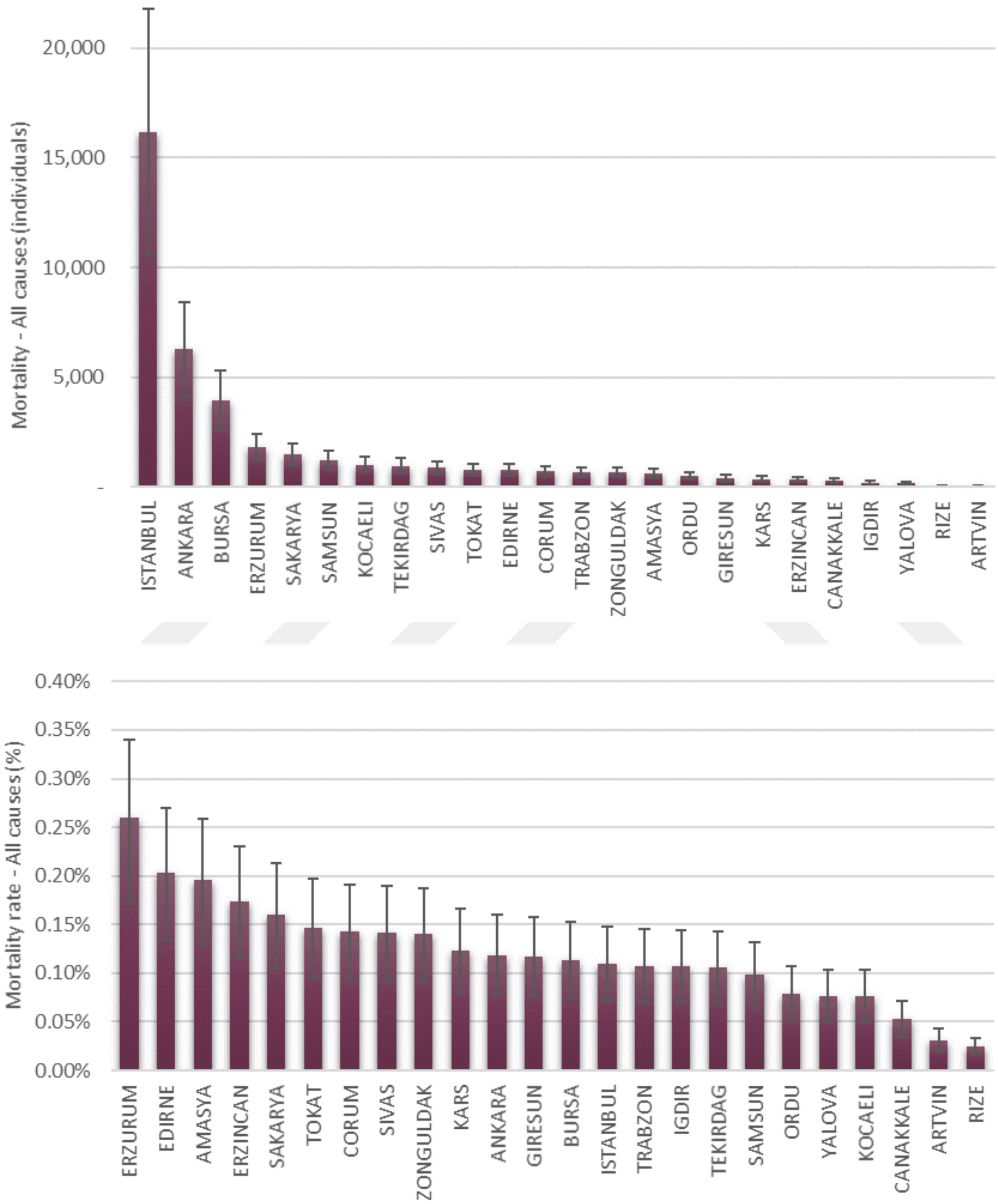

Figure 4.12 : Mortality by all causes diseases associated with $PM_{2.5}$ in 2016, Turkey, using ground measurement (upper individuals, below percentage).

Mortality by Ischemic Heart Diseases

The results show Istanbul as most estimated deaths associated with ground-measured $PM_{2.5}$ caused by IHD, although in percentage results which is calculated by dividing mortalities over population, Istanbul reaches 14th rank. Erzurum, Edirne and Amasya estimated the most at-risk populations.

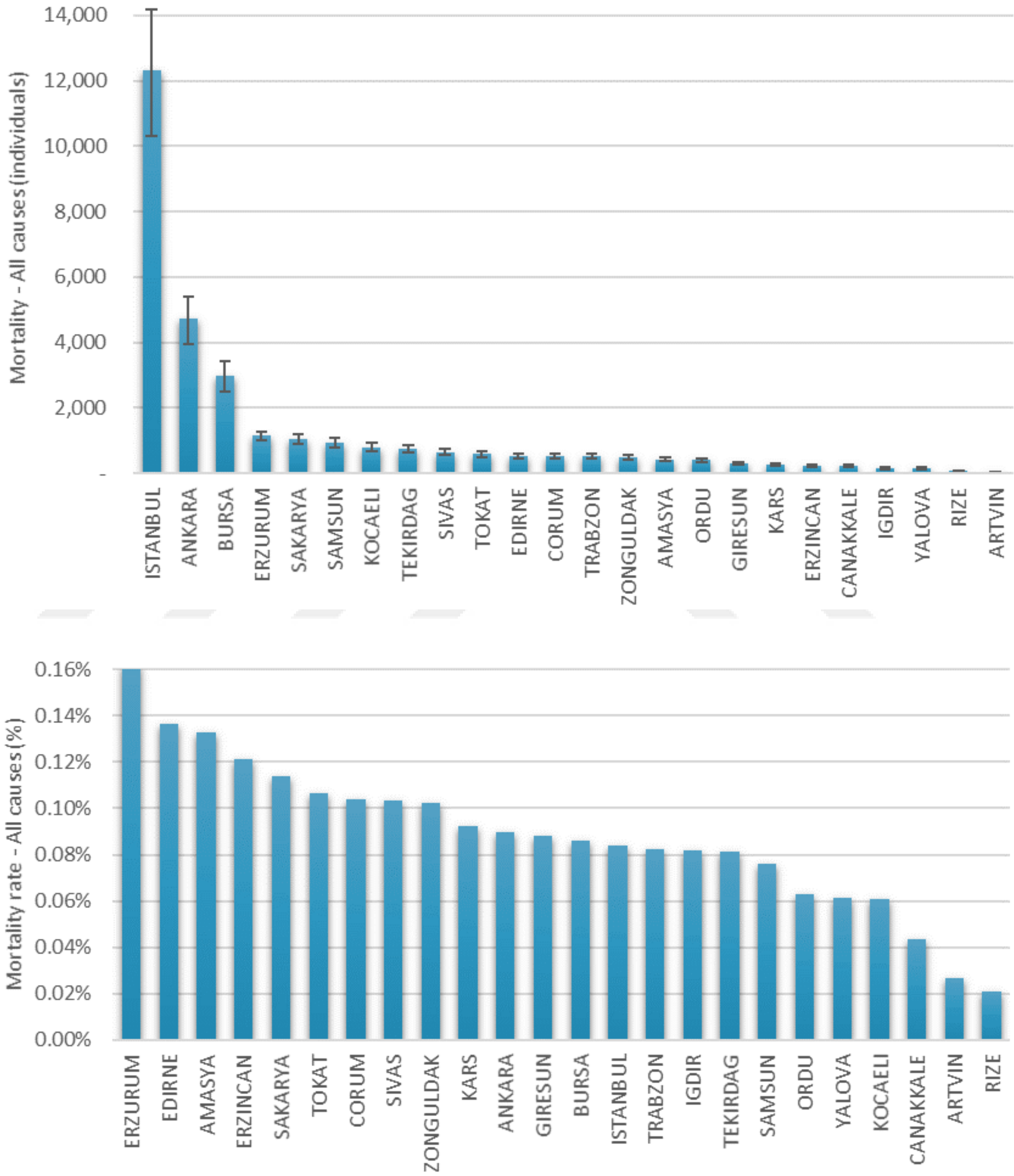

Figure 4.13 : Mortality by ischemic heart diseases associated with $PM_{2.5}$ in 2016, Turkey, using ground measurement (upper individuals, below percentage).

Mortality by Lung Cancer

The upper and lower bound shows a large range in LC results, especially in Istanbul. Although LC has lower deaths estimated in compare with IHD, the range is showing a higher uncertainty in LC mortality estimation.

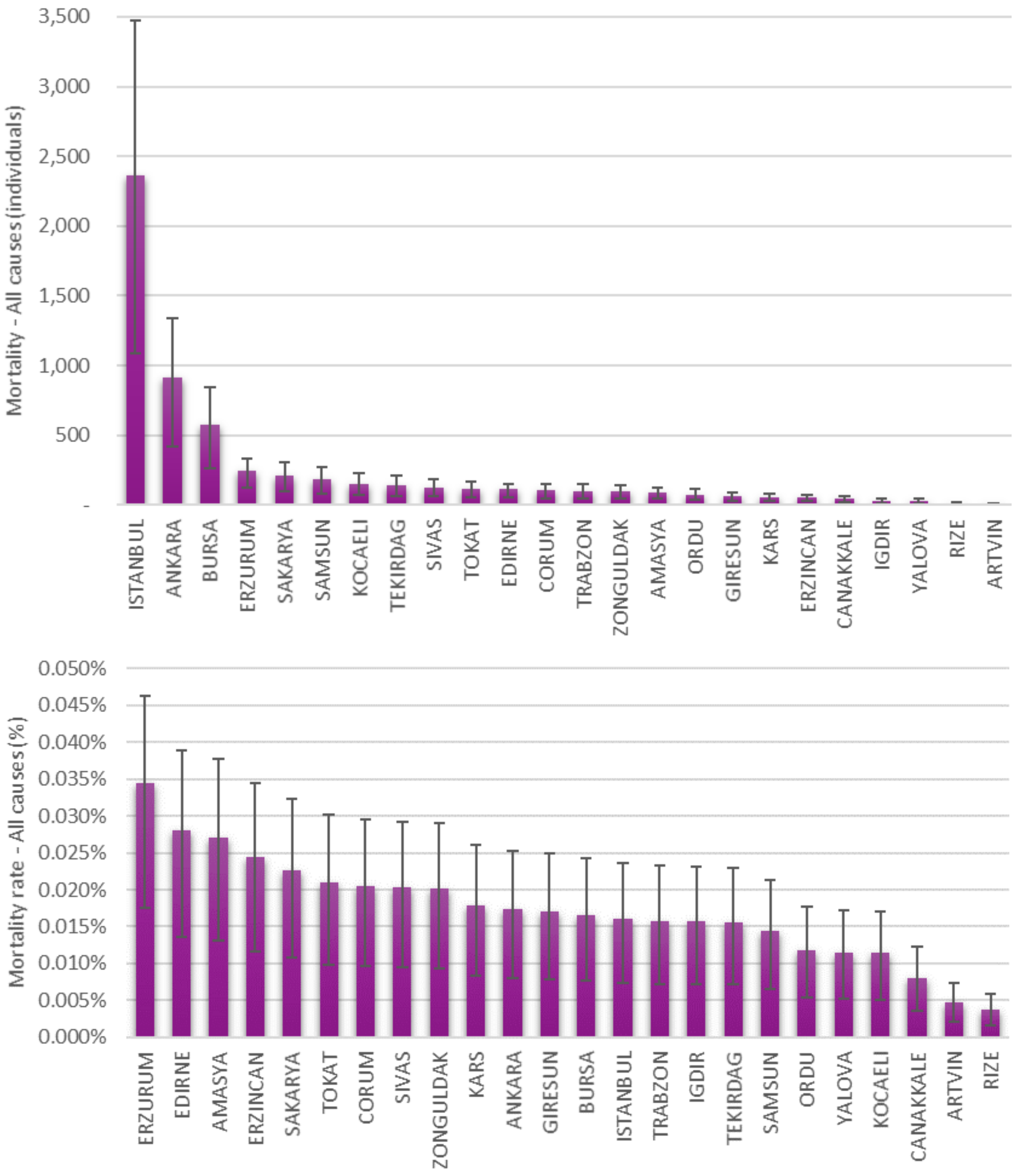

Figure 4.14 : Mortality by lung cancer associated with $PM_{2.5}$ in 2016, Turkey, using ground measurement (upper individuals, below percentage).

4.1.3 Health Risk Estimation using Satellite-Derived $PM_{2.5}$ with dust and sea-salt

To estimate the health effects using satellite derived dust and sea-salt included, the V4.GL.02 dust and sea-salt included product has been used. Accordingly, the maximum $PM_{2.5}$ concentrations has been raised to 64.8 and eventually it increased the number of mortalities up to 58 155 deaths. In this section, only the mortality caused by all causes and affected by $PM_{2.5}$ has been estimated and the other causes calculated by dust and sea-salt removed product would be change accordingly. Figure 4.15 shows the result of health effect estimations with salt and sea-salt included product in Turkey.

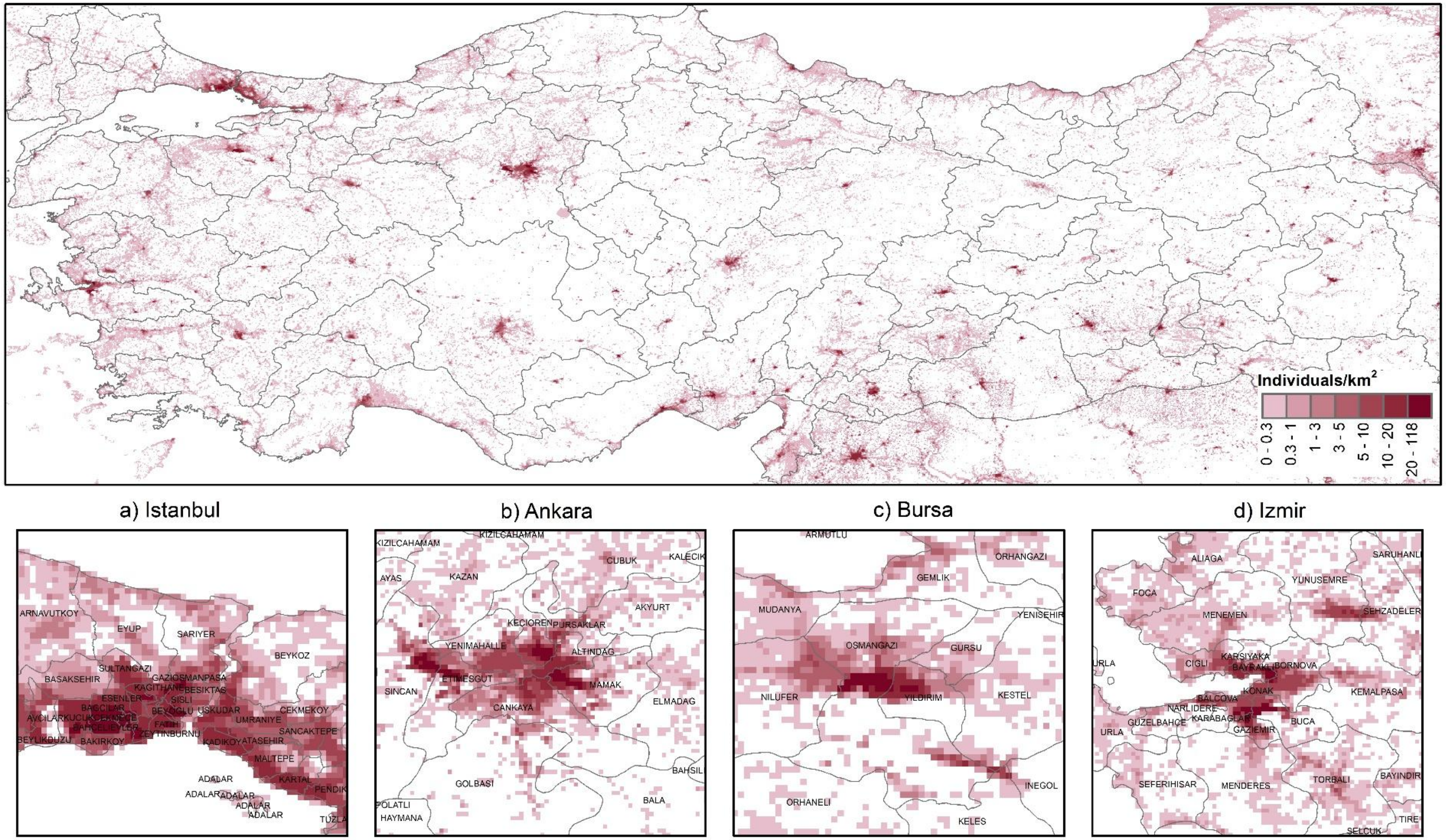

Figure 4.15 : The top panel shows spatial distribution of mortality associated with PM2.5 (dust and sea-salt included) caused by all causes in Turkey. Below panels showing the highest mortality rated cities of Turkey.

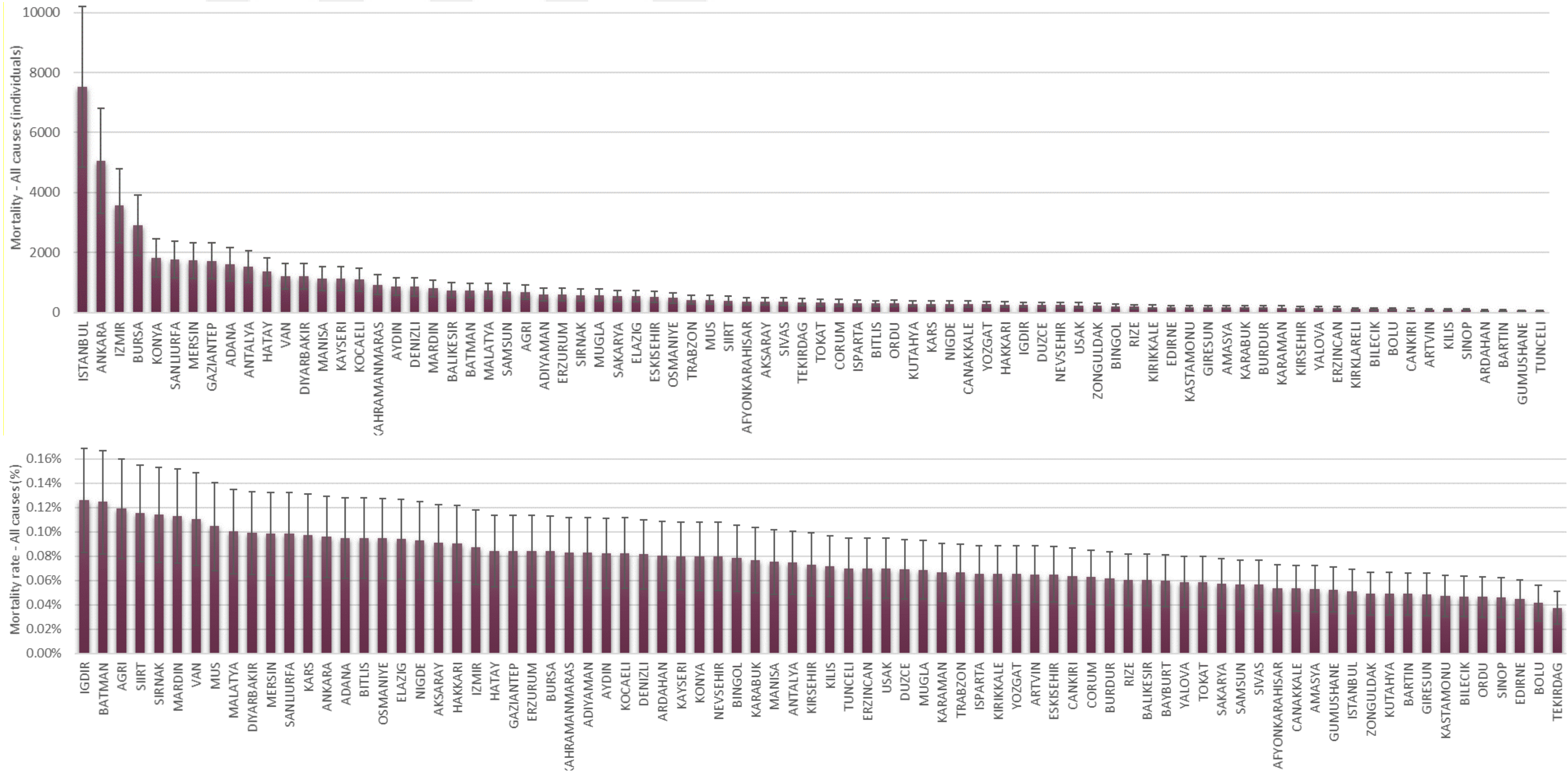

Figure 4.16 : Mortality by all causes associated with satellite-derived (dust and sea-salt included) PM2.5 in Turkey (2016) (upper individuals, below percentage).

4.2 $PM_{2.5}$ Pollution in Iran

Daily ground measurement data from DoE obtained and annually averaged by Excel and coordinates of the cities added as coordinates of the stations. The source of satellite data is the same for Iran as Turkey and it has clipped to Iran coordinates by ArcGIS clip management tool. The clipped file shows the minimum value as 3 $\mu g/m^3$, and the highest value as 28 $\mu g/m^3$. These values checked and it is within the country. The most representable classify for the satellite data was quantile feature of the ArcGIS.

There is an artifact on a grid in V4.GL.02 (van Donkelaar, 2018) product, which falls in east north of Iran and makes a bigger difference in values between East and West Azerbaijan and Ardebil provinces, and it might have increased the uncertainty in north east of Iran

Results show Iran's populated provinces such as Razavi Khorasan or Esfahan are not among top five results of this thesis. This might be through different source apportionment of $PM_{2.5}$ in different cities of Iran. It is assumed that western part of Iran has higher natural sources than center and east Iran.

To address the anthropogenic sources of $PM_{2.5}$ in Iran, the correlation between the population and the anthropogenic $PM_{2.5}$ has been calculated. shows the population and satellite $PM_{2.5}$ and the correlation between them.

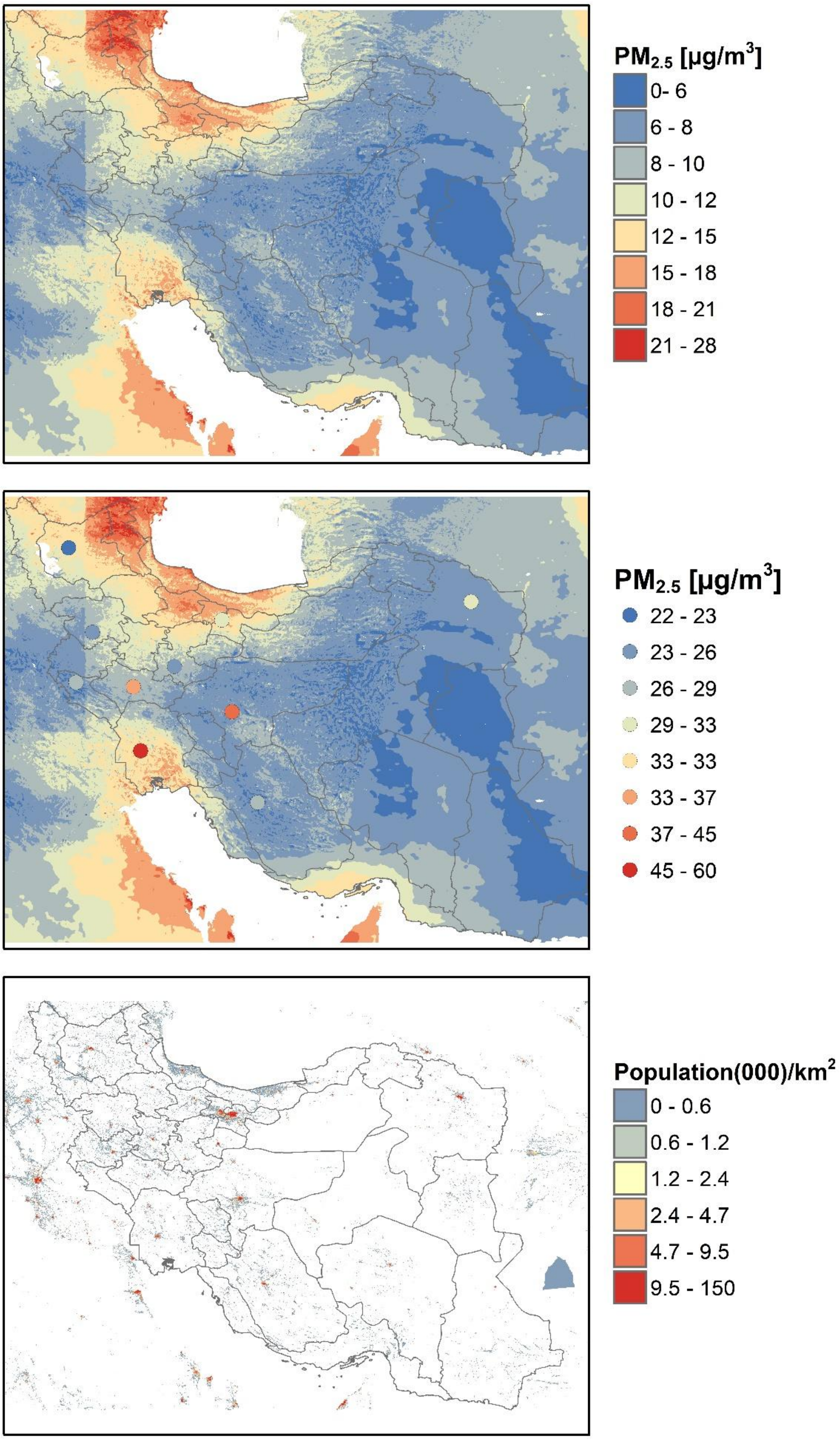

Figure 4.17 : Top panel shows satellite retrievals $PM_{2.5}$ over Iran in 2016, Middle panel shows ground station measurements in 2016 on the satellite retrievals background, Lower panel is the population distribution of 2015.

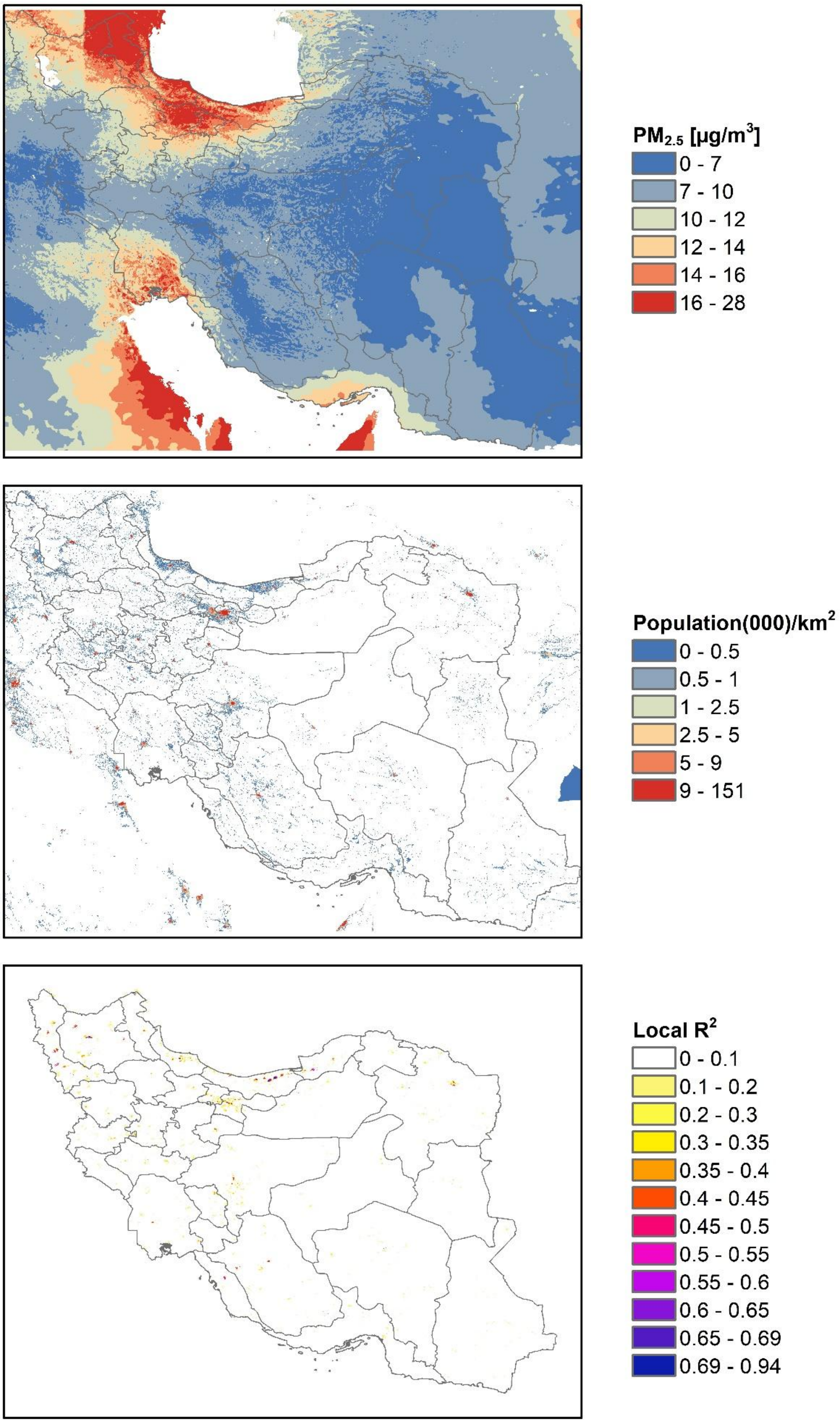

Figure 4.18 : Top panel shows satellite retrievals over Iran in 2016, Middle panel shows the population distribution in 2015, Lower panel shows the local R^2 between the two upper panels.

4.2.1 Health Risk Estimation using Satellite-Based $PM_{2.5}$

The same method as for Turkey used to calculate health effects of anthropogenic $PM_{2.5}$ in Iran. The same concentration-response factors have been used to be calculated with the population distribution. The differences between two countries calculations are baseline mortalities and background concentration (X_0). Since X_0 is the lowest observed concentration in the study region, for Iran the value 3 has been used.

indicates Tehran the capital, has the most at risk population in Iran with estimated 5148 deaths by all causes and attributed with $PM_{2.5}$. Although mortality percentage ranks some unexpected cities in top five provinces with the population at risk, such as Ardebil and Gilan or Mazandaran. Gilan and Mazandaran are located in the greenest and vegetated region of Iran, and not as industrialized as Qazvin or Alborz, and not as populated as Tehran or Esfahan. Thus it is surprising to see them in top five most at-risk populations of Iran. Although when new published measurements of Gilan's single station measuring $PM_{2.5}$ compares to the other stations, Gilan observes as most polluted provinces of Iran. However, DoE does not measure either $PM_{2.5}$ or PM_{10} in Mazandaran province, which has similar meteorology and results with Gilan in this study. Therefore the uncertainty of satellite retrievals over this region remains unknown.

Mortality by all causes

Following figures show the mean and upper-lower estimated bounds of spatial distribution of all causes mortality associated with $PM_{2.5}$ in Iran and most at risk provinces. The city Ahvaz in Khuzestan province shown with city labels and more magnified than other provinces.

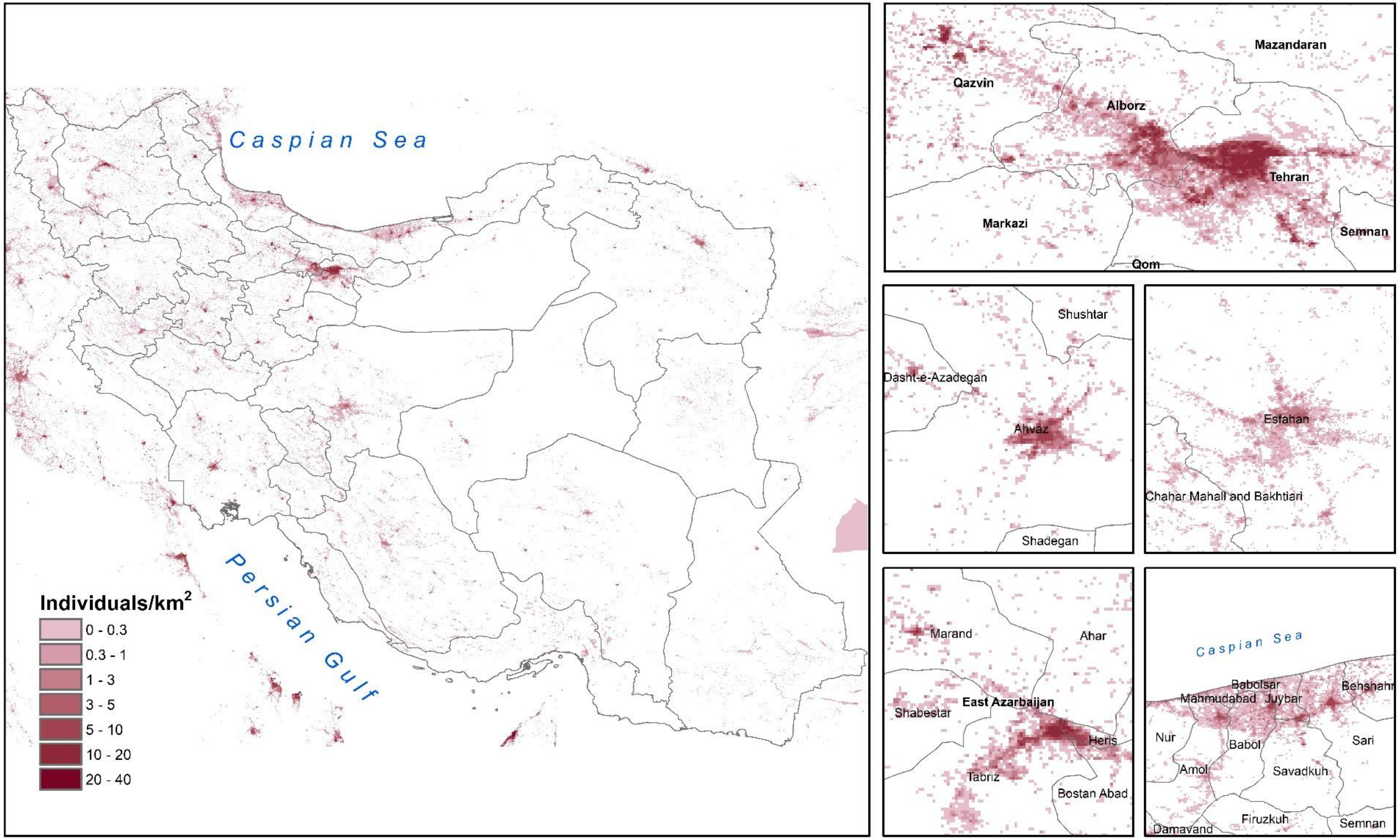

Figure 4.19 : The left panel shows spatial distribution of estimated mortality associated with $PM_{2.5}$ by all causes in Iran. Right-top panel showing the highest mortality rated cities of Iran; Ahvaz, Tehran and Alborz, Esfahan, East Azerbaijan, Mazandaran.

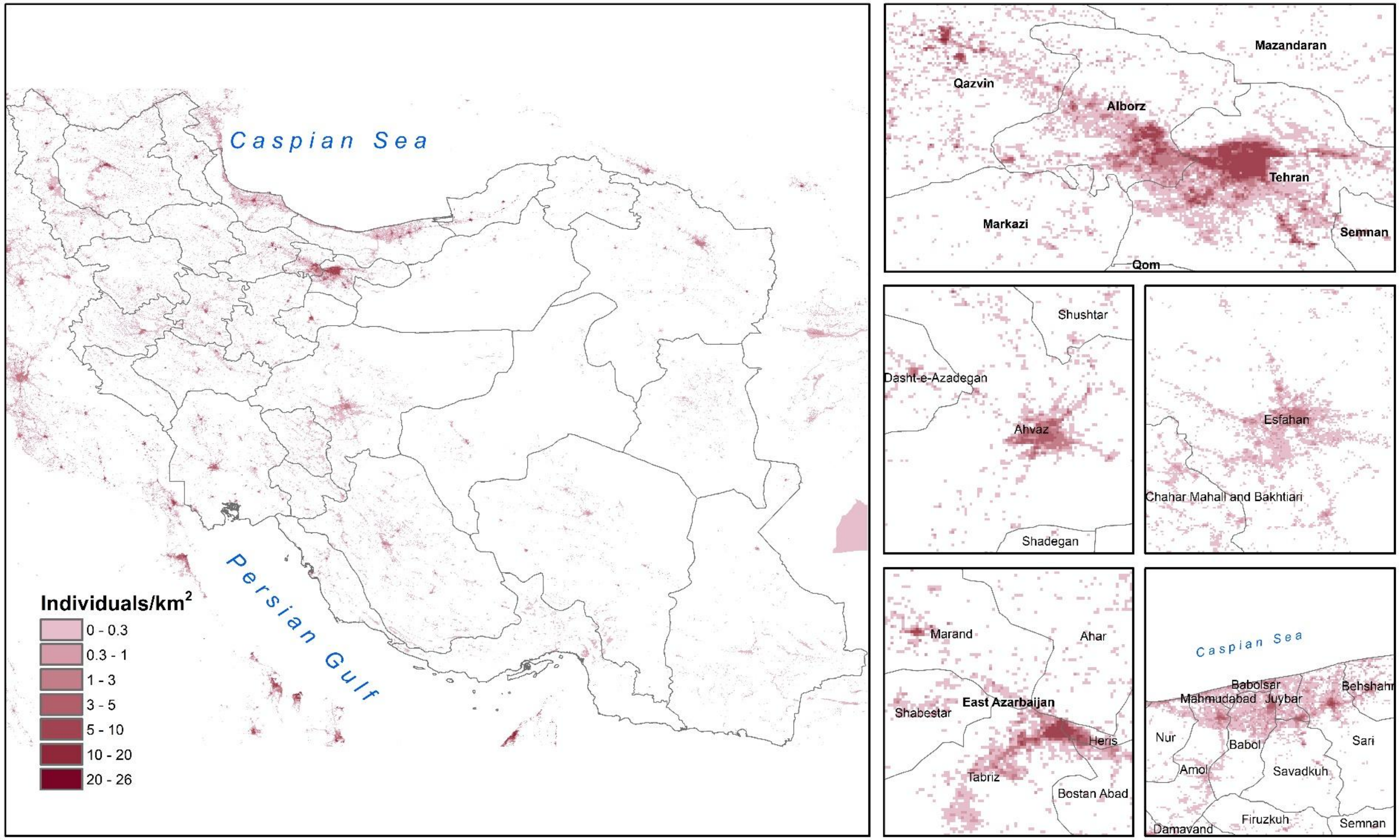

Figure 4.20 : The left panel shows spatial distribution of lower estimated mortality associated with $PM_{2.5}$ by all causes in Iran. Right-top panel showing the highest mortality rated cities of Iran; Ahvaz, Tehran and Alborz, Esfahan, East Azerbaijan, Mazandaran.

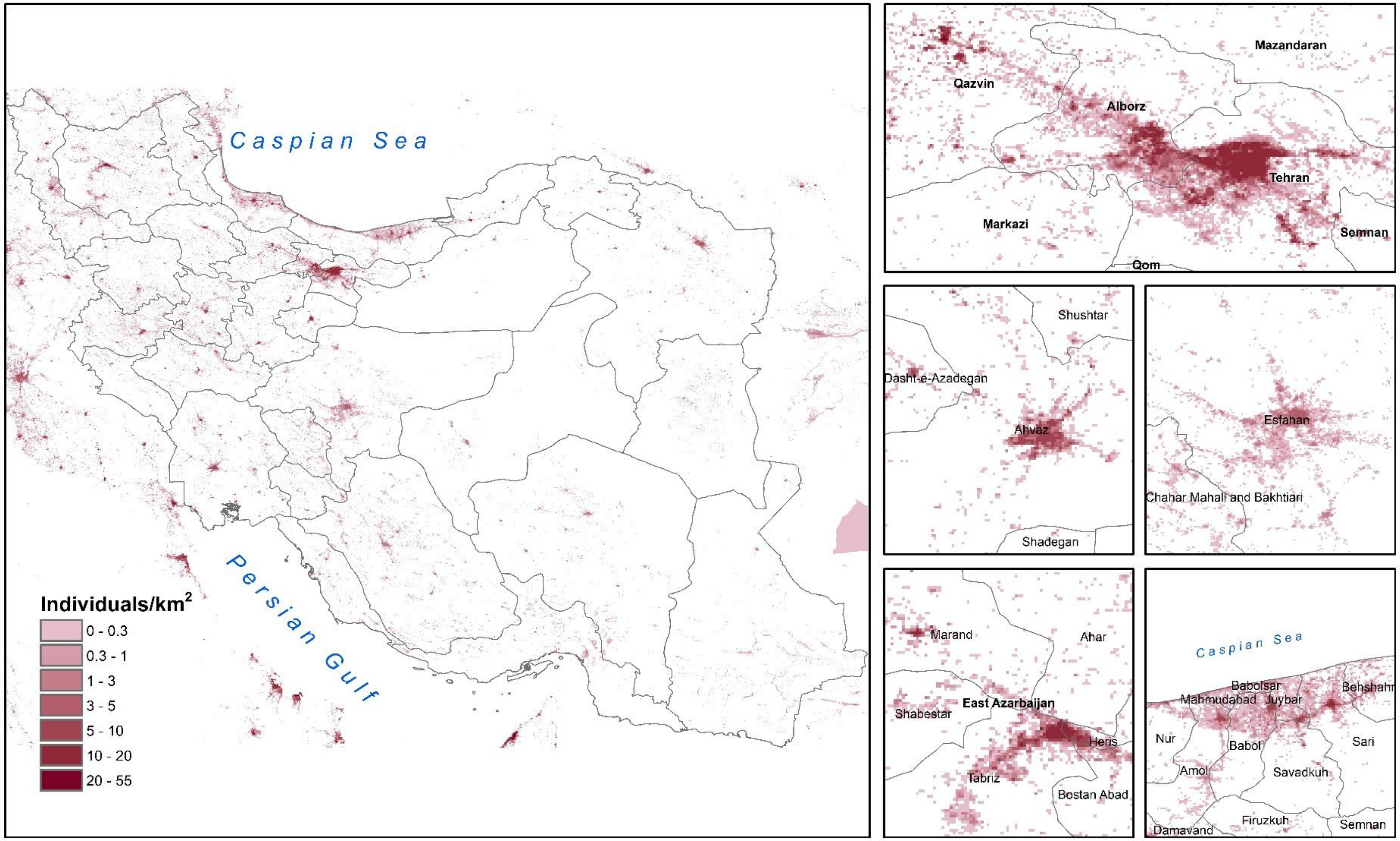

Figure 4.21 : The left panel shows spatial distribution of upper estimated mortality associated with $PM_{2.5}$ by all causes in Iran. Right-top panel showing the highest mortality rated cities of Iran; Ahvaz, Tehran and Alborz, Esfahan, East Azerbaijan, Mazandaran.

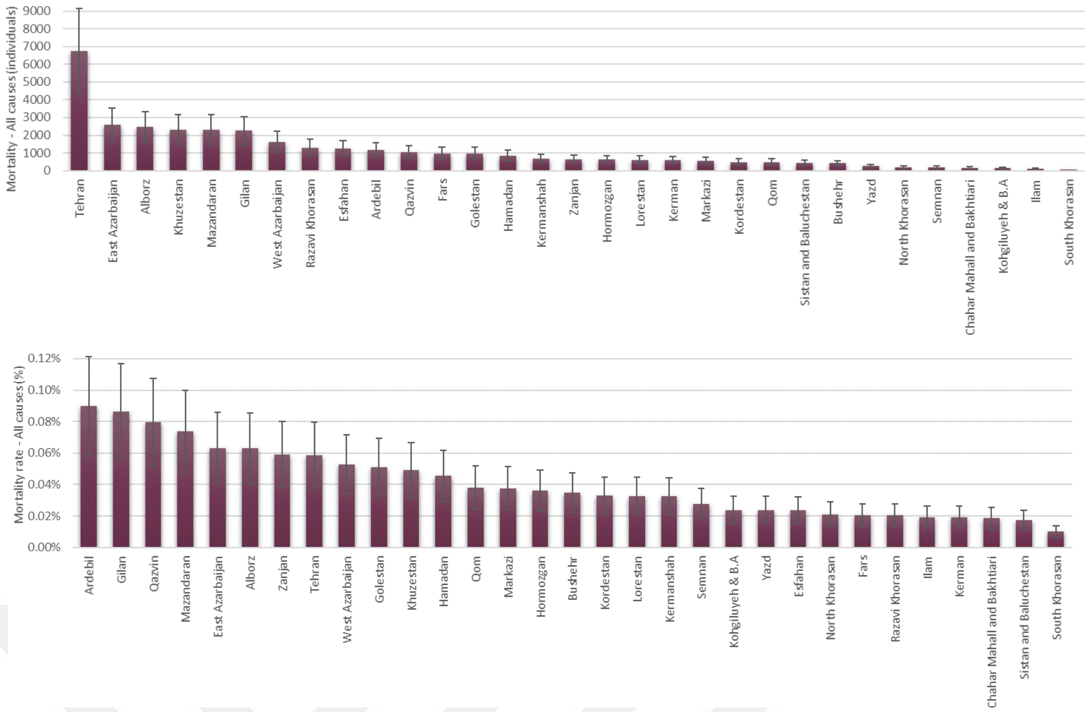

Figure 4.22 : Mortality caused by all causes associated with satellite-derived $PM_{2.5}$ in Iran (2016) (upper individuals, below percentage).

Mortality by Ischemic Heart Diseases

Likewise, in estimated all causes associated mortalities, Ardebil, Qazvin, Gilan, Mazandaran, and Alborz are most at risk cities in IHD caused mortalities estimations.

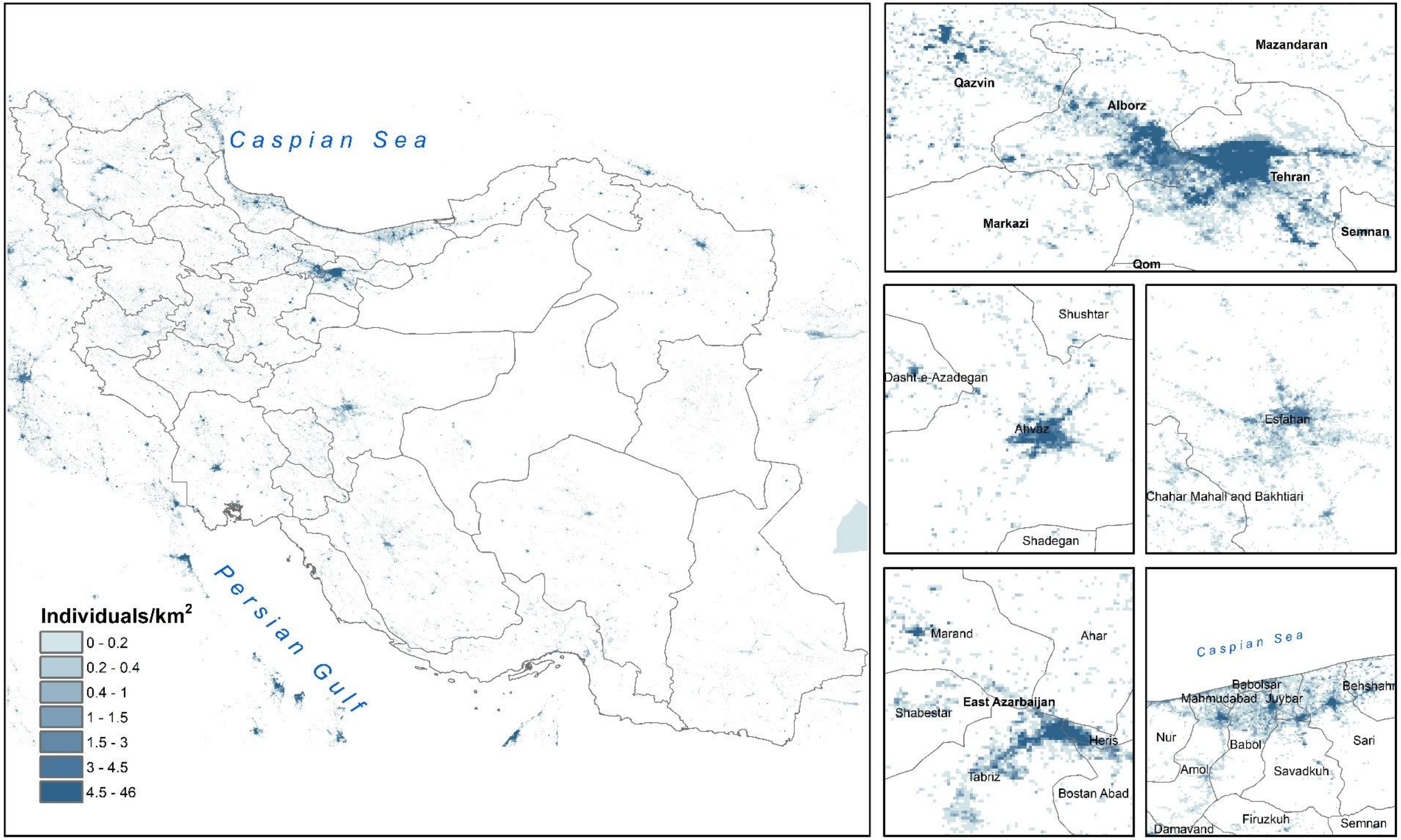

Figure 4.23 : The left panel shows spatial distribution of estimated mortality associated with $PM_{2.5}$ by all causes in Iran. Right-top panel showing the highest mortality rated cities of Iran; Ahvaz, Tehran and Alborz, Esfahan, East Azerbaijan, Mazandaran.

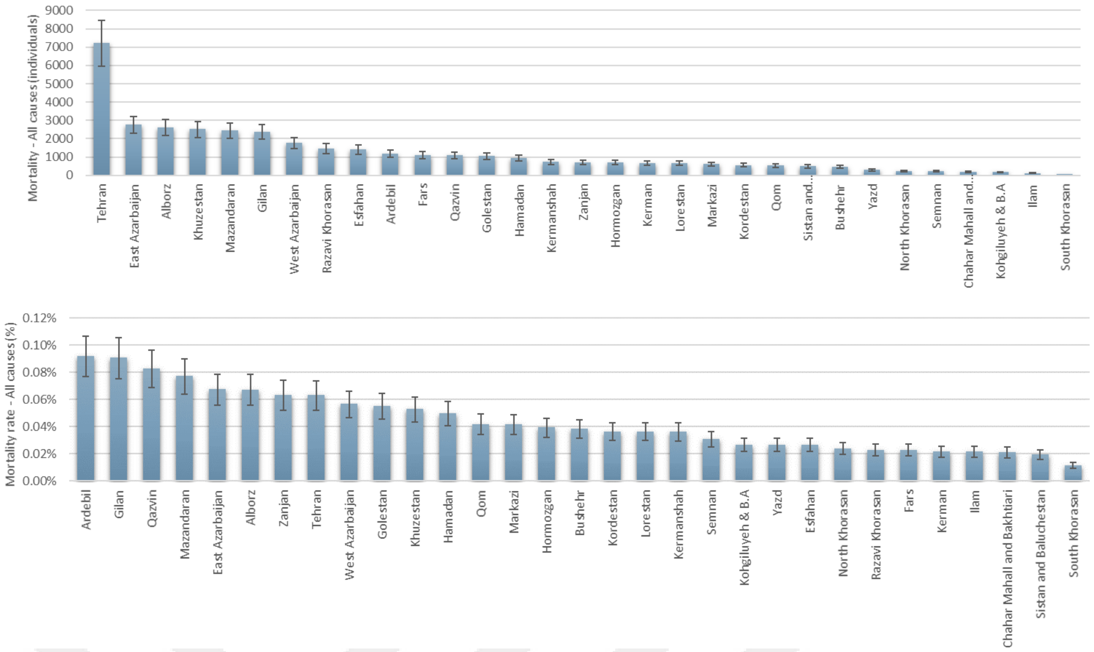

Figure 4.24 : Mortality caused by ischemic heart diseases associated with satellite-derived $PM_{2.5}$ in Iran (2016) (upper individuals, below percentage).

Mortality by Lung Cancer

Lung cancer mortality rates reported much lower in Iran, and the estimated deaths sequently were almost one-tenth of Turkey.

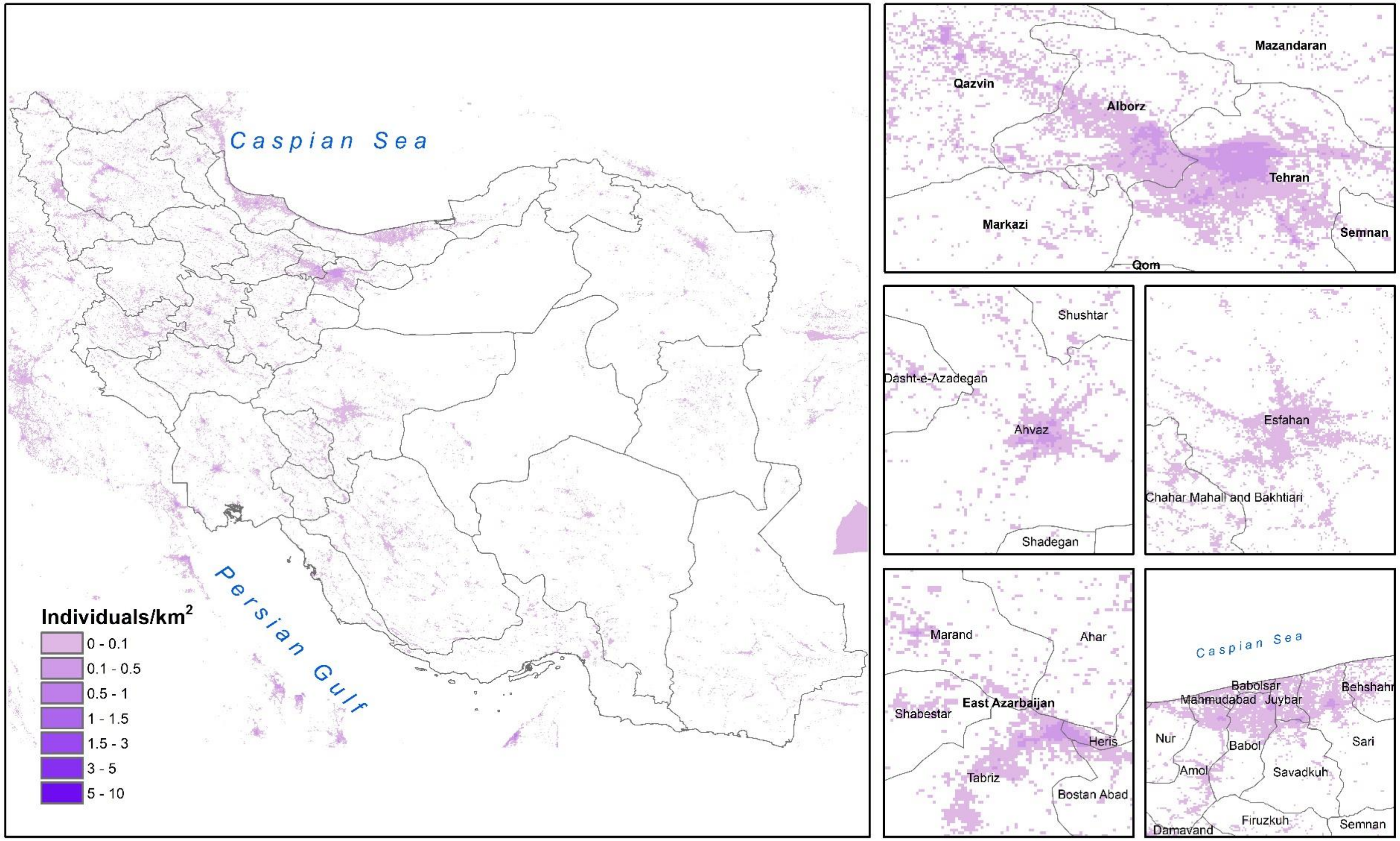

Figure 4.25 : The left panel shows spatial distribution of estimated mortality associated with $PM_{2.5}$ by all causes in Iran. Right-top panel showing the highest mortality rated cities of Iran; Ahvaz, Tehran and Alborz, Esfahan, East Azerbaijan, Mazandaran.

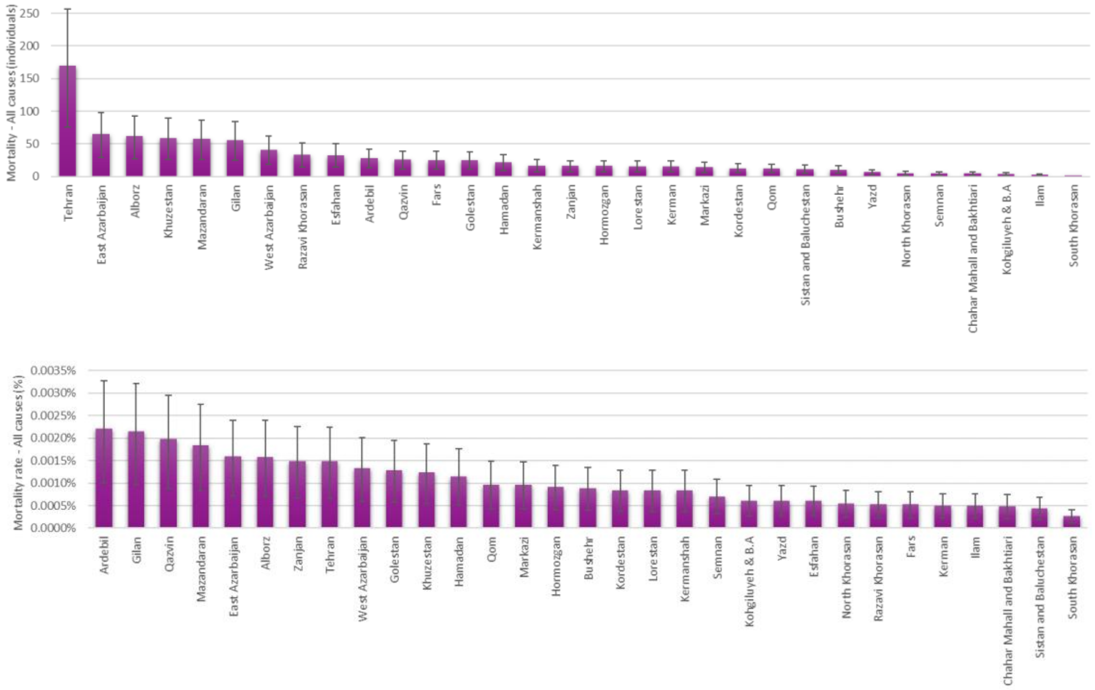

Figure 4.26 : Mortality caused by lung cancer associated with satellite-derived $PM_{2.5}$ in Iran (2016) (upper individuals, below percentage).

4.2.2 Health Risk Estimation using Ground-Based $PM_{2.5}$

The ground $PM_{2.5}$ measurements of Iran requested from DoE by ITÜ, but to this date still it is under the process of DoE and for this reason, data from literature has been used. In the literature (Hadei et al., 2017), data from 2013 to 2016 is reported, and no ground measurement is available for the year 2016 so far.

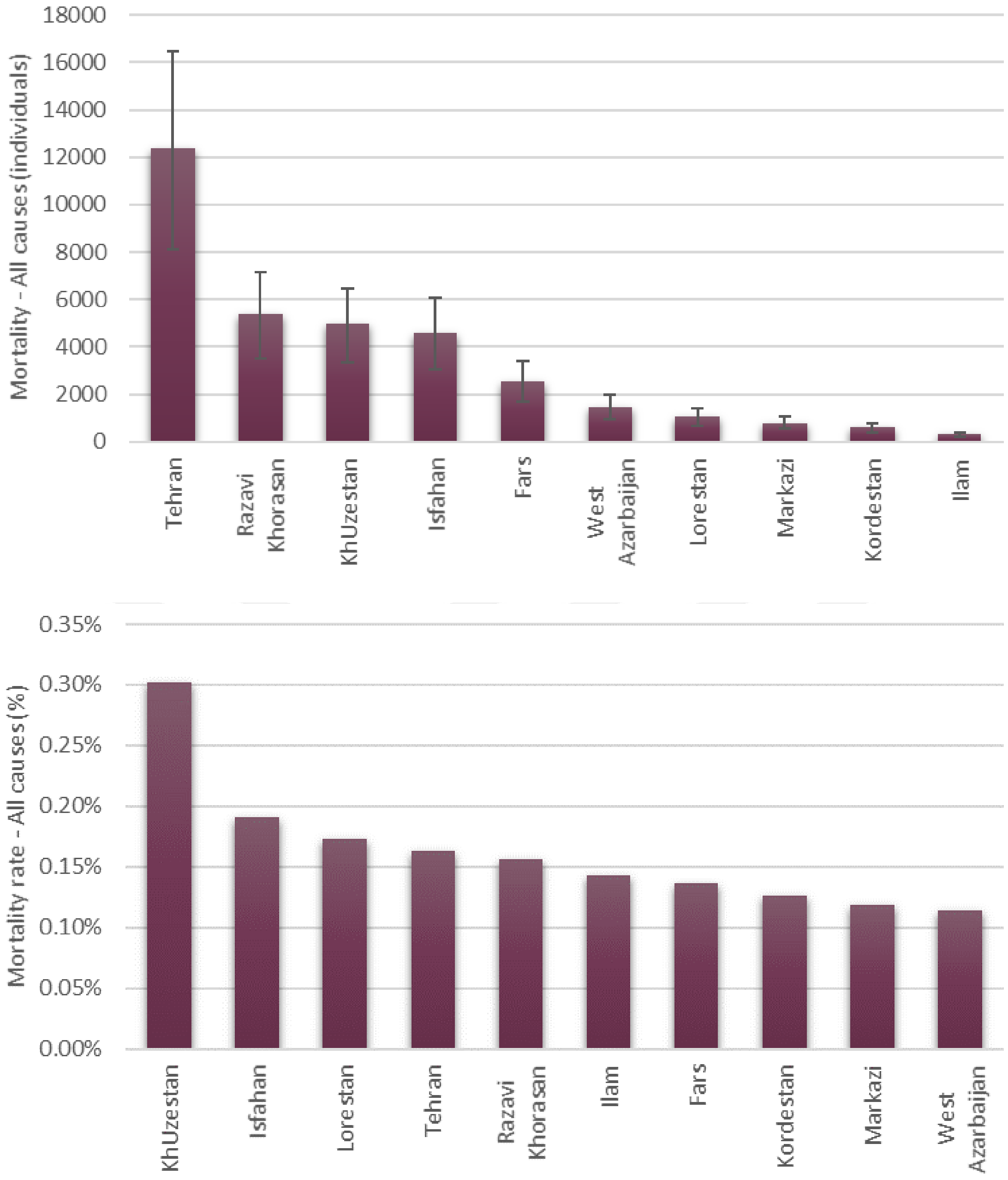

Figure 4.27 : Mortality by all causes associated with $PM_{2.5}$ in 2016, Iran, using ground measurement (upper individuals, below percentage).

The correlation between ground $PM_{2.5}$ measurements and satellite-derived dust and sea-salt removed data shown in Figure 4.28. However, the correlation is higher by excluding one outliner station with a value more than 60.

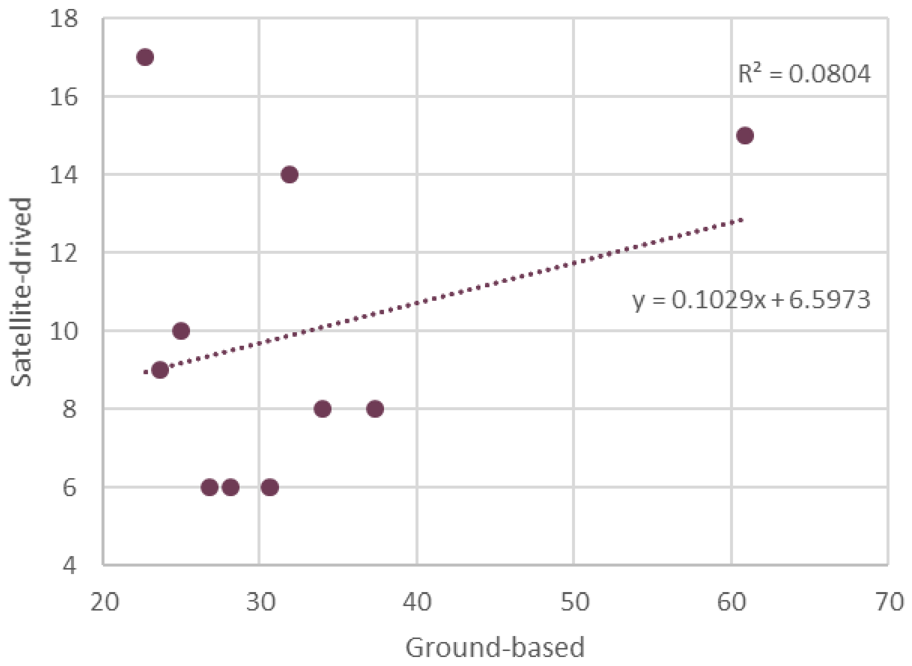

Figure 4.28 : Ground measurement vs Satellite-derived data of Iran (2016).

Mortality by Ischemic Heart Diseases

The calculations for estimated mortalities caused by IHD, was done with calculating baseline mortality caused by IHD. The baseline for Iran (0.003195) was significantly higher than Turkey (0.002481). Therefore, Iran has higher mortalities associated with $PM_{2.5}$ caused by IHD than Turkey.

In Iran, Khuzestan's mortality percentage is still the highest, following with Isfahan, Lorestan and Tehran.

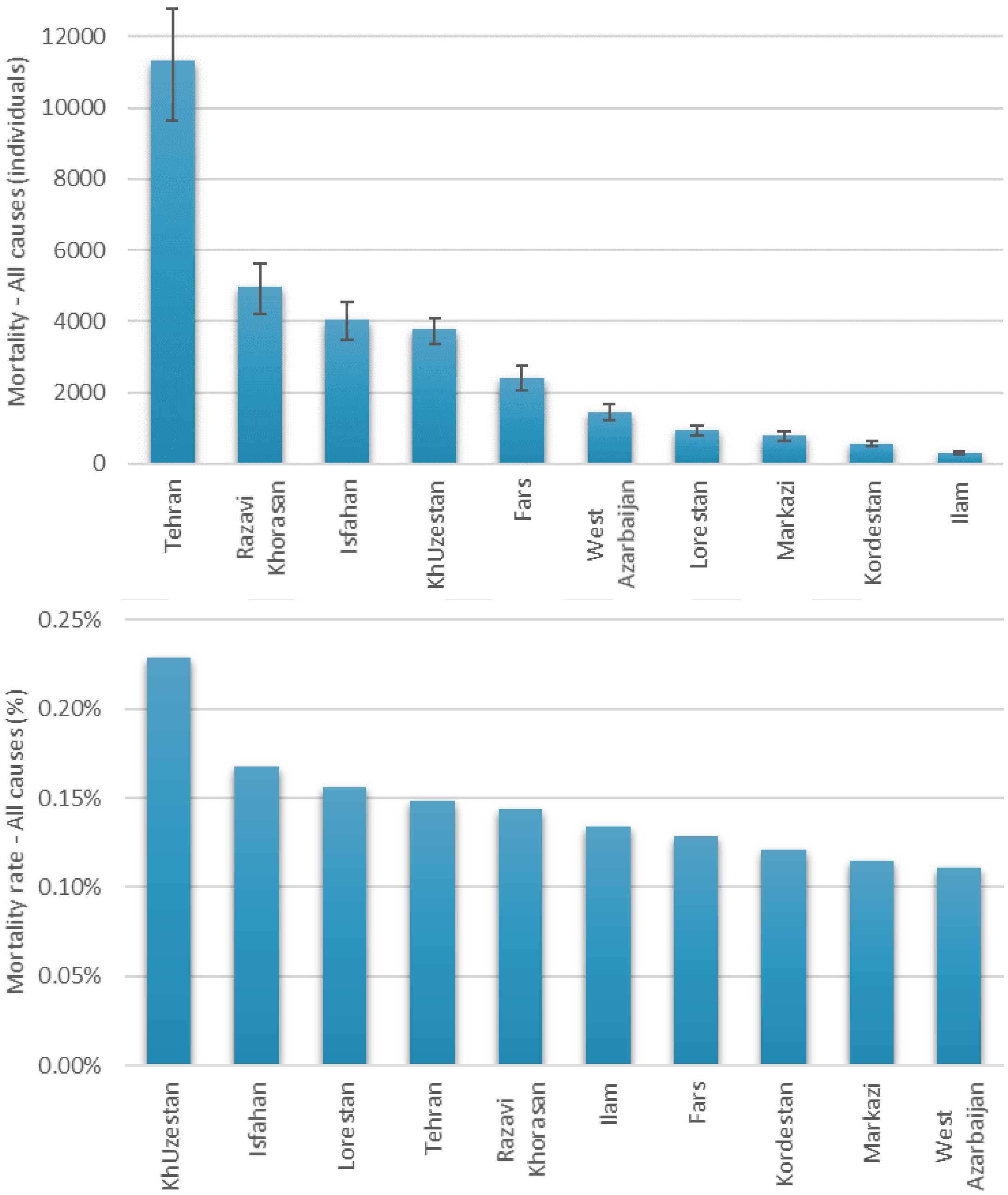

Figure 4.29 : Mortality by ischemic heart diseases associated with $PM_{2.5}$ in 2016, Iran, using ground measurement (upper individuals, below percentage).

Mortality by Lung Cancer

Lung cancer baseline mortality in Iran was so low, but the ground-based mortality results are still higher than Turkey. In Tehran, 284 individuals estimated to lose their lives due to anthropogenic $PM_{2.5}$. The results are significantly higher than satellite-based calculations

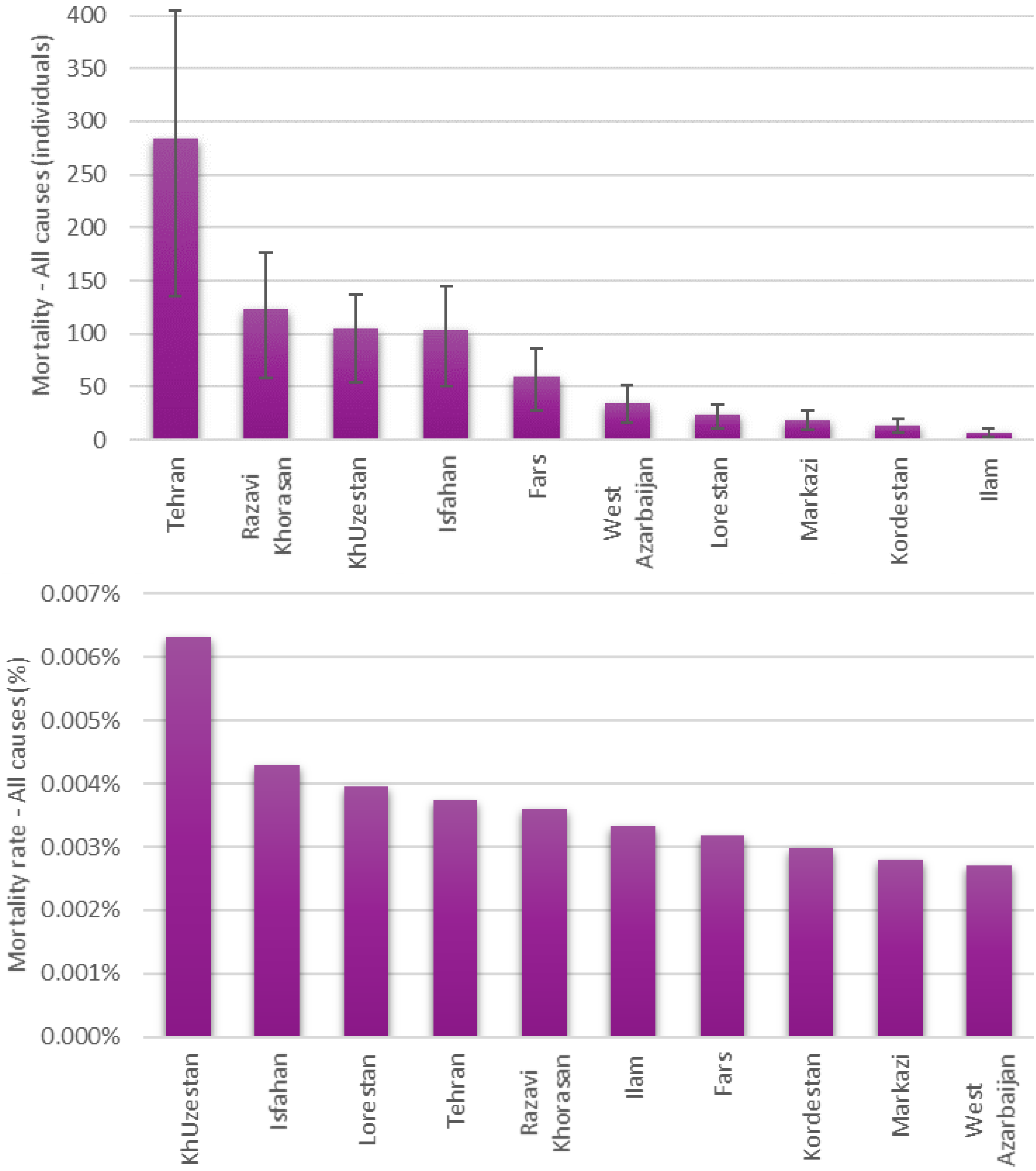

Figure 4.30 : Mortality by lung cancer associated with $PM_{2.5}$ in 2016, Iran, using ground measurement (upper individuals, below percentage).

4.2.3 Health Risk Estimation using Satellite-Derived $PM_{2.5}$ with dust and sea-salt

The importance of satellite considering dust and sea-salt in such health effect estimations, for countries such as Iran which are experiencing dust events so often is more than Turkey or countries with less dust events. The results of this estimations showing a significant increase in mortalities. In provinces such as Khuzestan, which is the hotspot of dust events in Iran, mortalities increased almost 5 times than without salt and sea-salt product based estimations. Figure 4.31 shows the spatial distribution of mortalities caused by all causes affected by $PM_{2.5}$.

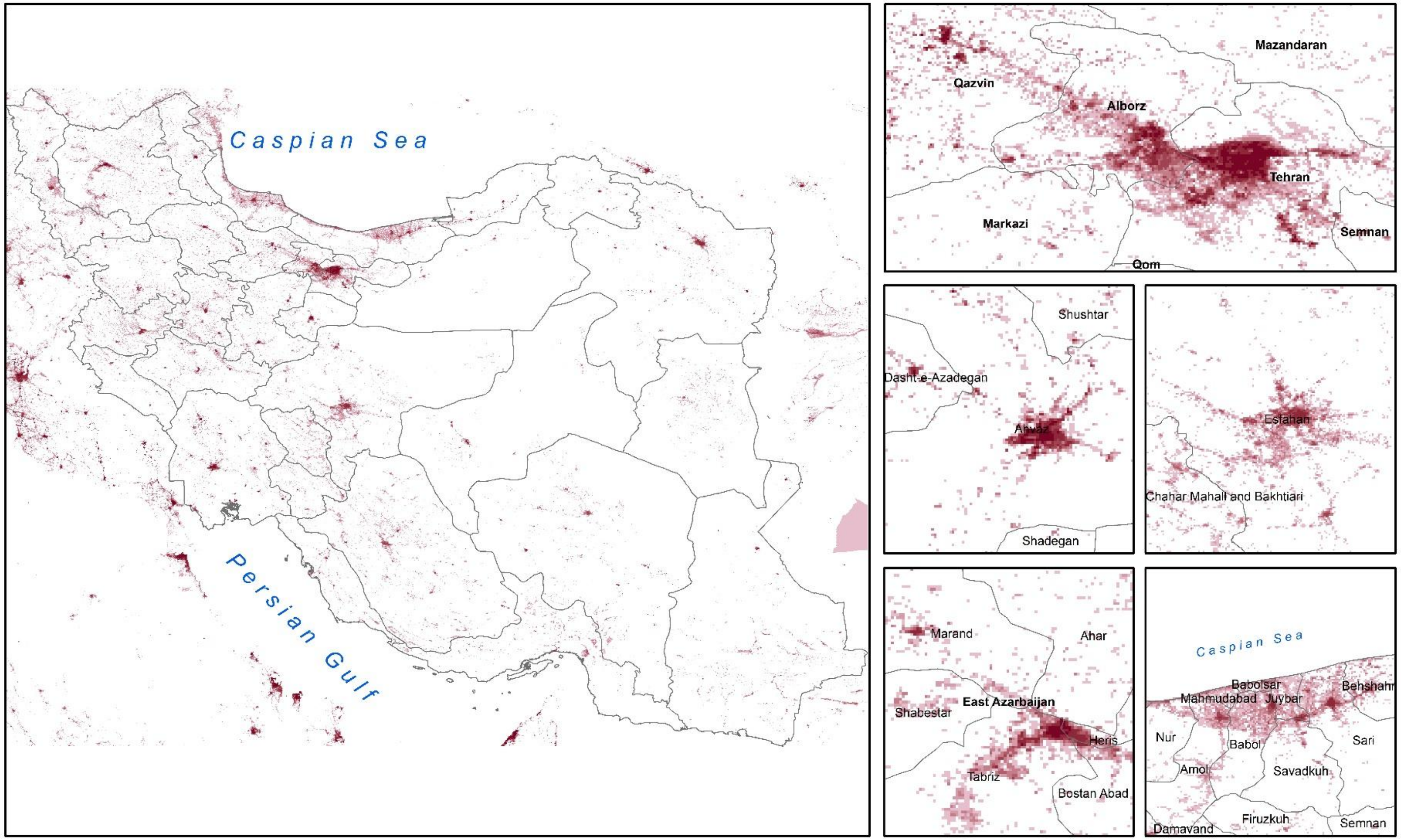

Figure 4.31 : The left panel shows spatial distribution of estimated mortality associated with PM2.5 by all causes in Iran. Right-top panel showing the highest mortality rated cities of Iran; Ahvaz, Tehran and Alborz, Esfahan, East Azerbaijan, Mazandaran.

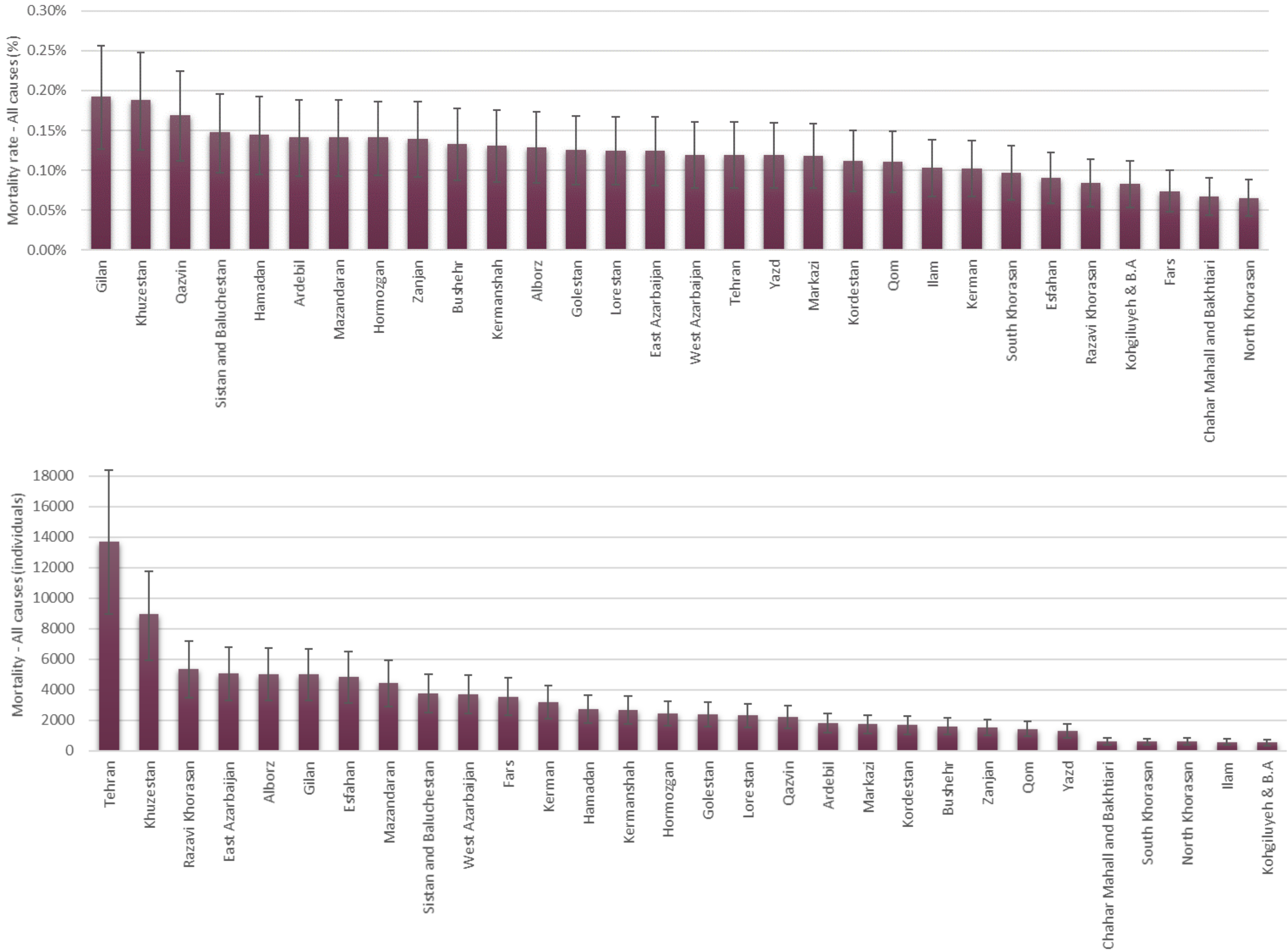

Figure 4.32 : Mortality caused by all causes associated with satellite-derived (dust and sea-salt included) $PM_{2.5}$ in Iran (2016) (upper individuals, below percentage).

4.3 Comparison of Turkey and Iran

The summary of this study's results shows lower estimated mortalities associated with $PM_{2.5}$ in Iran than Turkey. Lack of reported ground measurement data would be one of the reasons, although DoE reports over 21 Stations to WHO regularly. Although in Health Effects Institute's annual ambient air pollution, estimations are lower in Iran than Turkey. However, in the report of Institute of Health Metrics and Evaluation (IHME) Iran's estimated mortality associated with $PM_{2.5}$ is almost a thousand individuals more than Turkey.

By using the dust and sea-salt satellite-derived dataset, due to high dust and sea salt concentrations in Iran, as it showed in Figure 3.4, total mortalities in Iran increases to 95 618 deaths is prominent in this thesis. However, the uncertainty for this prominent result is high due to the difference in dust and sea-salt concentration in Iran and the country that the concentration-response factor has been conducted. As dust and sea-salt having not the same effect on human being health as anthropogenic $PM_{2.5}$, using the same concentration-response factor for countries having more dust and sea-salt concentrations increases the uncertainty.

Table 4.1 : Summary of mortality associated with $PM_{2.5}$ in Iran and Turkey, and reported references.

Causes	Turkey		Iran		Reference
	Satellite	Ground*	Satellite	Ground**	
All causes ***	58 155 (78 474, 37 766)	40 583 (26 493, 54 472)	95 618 (12 7937, 128 618)	33 203 (21 900, 44 107)	This study
All causes	36 967 (23 848, 50 220)		34 491 (46 853, 22252)		This study
Ischemic heart diseases	30 240 (35 599, 25 076)	30 357 (25 525, 34 774)	37 368 (43 732, 30 732)	30 562 (26 156, 34 428)	This study
Lung cancer	5 591	5 884 (2 723, 8 574)	871 (387, 1 321)	776 (372,1 095)	This study
All causes	27 103		28 716		HEI (2016)
All causes	32 668		26 267		WHO (2012)
All causes	28 785		29 661		IHME (2016)

* out of 35 024 768 individuals, living in reported provinces.
** out of 20 288 129 individuals, living in reported provinces.
*** using satellite retrievals with dust and sea-salt.

5. CONCLUSIONS AND FUTURE WORKS

The advantage of studying anthropogenic $PM_{2.5}$, is to have a better prioritizing in decision making and legislation. However, $PM_{2.5}$ pollution in Iran is affected almost five times more by natural sources than Turkey (Lelieveld et al., 2015), especially in western and south-west provinces of Iran such as Khuzestan. Having high estimated mortality associated with $PM_{2.5}$ in Khuzestan province of Iran, shows sources such as petroleum industries in this province are responsible for a mentionable portion of mortalities. Likewise, the middle regions of Turkey due to the industrialization of the region has serious adverse health effects.

In the year 2016, approximately 37 000 deaths in Turkey and 27 250 deaths in Iran were estimated to be associated with satellite-derived $PM_{2.5}$. With respect to the fact that both countries having almost the same population, the difference in estimated mortality is significantly large. The first reason for that difference highly probably because of the higher baseline mortality in Turkey than Iran, as it is almost incomparable in LC's baseline mortality. The other reason might be due to fossil fuel type that uses in energy production industries which is mostly natural gas in Iran and coal in Turkey, or the majority of diesel cars in Turkey, while diesel consumption is limited to heavy vehicles in Iran and the rest of vehicles consuming either benzin or CNG.

Top four most at risk population provinces of Turkey is the most populated provinces of the country as well. However, in Iran, it is not the same, populated provinces such as Razavi Khorasan or Esfahan are not among top five results of this thesis. This might be through different industry distribution pattern in Turkey and Iran, as the most industrialized provinces in Iran are not the most populated ones.

In eastern Turkey, it seems to be an emission travel between the Northern Syria and Iraq, to Armenia, and meanwhile, cities such as Igdir in Turkey are experiencing high mortalities sequentially. Likewise, Khuzestan and other western cities of Iran are affected by dust events which have sources based in Syria and Iraq (NASA, 2015).

The uncertainty of used satellite retrievals makes the correlation between ground and remote sensing measurements very low. This might be due to both conversions from AOD to $PM_{2.5}$, and from $PM_{2.5}$ to dust and salt removed product. However, in Turkey's results by removing four high reported cities by MoEU, the correlation increases significantly. Also, in ground measurement based calculations of this thesis, it is assumed that the whole province's population are exposuring the same concentration as reported by MoEU. However, insufficient stations in both countries especially in Iran, do not let such studies compare and correlate satellite retrievals with ground measured concentrations. Furthermore, the population dataset used in this thesis, has produced by modeling with minor uncertainties, and the latest version which used is for the year 2015. The population data checked with TUIK, WHO, SCoIR, and the difference was less than 1million in each country's population.

Such long-term exposure studies need to be done by using exposure-response functions calculated by local cohort studies, to estimate more precisely. Although, due to more uncertainties in long-term studies, short-term studies are more preferred by policy makers.

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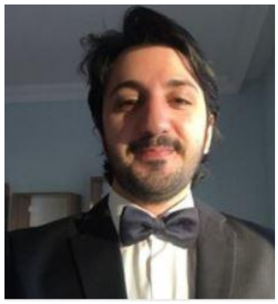
CURRICULUM VITAE



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