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Ground Air Quality for Ankara, Turkey, Monitored from Space and City Mortality for the Interval 2009 – 2016

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Abstract: Introduction: With an advancement of space technology, it is possible to monitor the quality of the ground air on large areas of the earth's surface, in particular, tracking the average air quality over large cities with millions of inhabitants.
Goal: Searching for an answer to the question: "Is it possible to monitor the dependence of mortality in large urban centers by the air quality in them through satellite monitoring?"
Material and Methods: Statistics on annual mortality in major Turkish cities were derived from Turkey's national statistics website. Data on 22 meteorological parameters and pollutant concentrations in the ground air for the Ankara area measured by satellite-based appliances were derived from a NASA site. The data were examined for the existence of statistically significant correlations between mortality rates in the city of Ankara and the meteorological parameters and concentrations of ground air pollutants.
Results: The change in mortality from respiratory diseases in Ankara closely follows the change in atmospheric pressure over the years (correlation coefficient +0.966, significance level 0.001). The correlation coefficient of methane concentration with atmospheric pressure is +0.970, a significance level of 0.001, and the correlation coefficient of methane concentration with respiratory mortality in Ankara is +0.938, a significance level of 0.01. Methane concentration has a statistically significant correlation coefficient also with the mortality from neoplasms (0.768, statistically significant for level 0.05), cardiovascular diseases (0.861, statistically significant for level 0.05), neoplasms (0.772, statistically significant for level 0.05), and diseases of the nervous system and sensory organs (0.827, statistically significant for level 0.05). Mortality in Ankara from cardiovascular diseases also has a large correlation coefficient (+0.941, significance level 0.01) with the parameter uv aerosol index, characterizing the presence of aerosols in the ground air. Statistically significant correlation coefficients of the mortality in Ankara with air quality parameters over the city measured by satellites were found for four out of six groups of causes of death – respiratory diseases, cardiovascular diseases, neoplasms, and diseases of the nervous system and sensory organs.
Discussion: It turned out that the air pollutant, whose concentration correlates most with atmospheric pressure and mortality in Ankara, is methane. The liquid aerosol with dissolved NO_2 probably contributes to the mortality in Ankara also.

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for the type of aerosol can be judged by the correlation coefficients of the index with the concentrations of other air pollutants.

Key words: Urban Air Pollution, Environmental monitoring from Space, Mortality, Ankara, Methane, UV Aerosol Index

1. Introduction

Introduction: With an advancement of the Space Technology, it is possible to monitor the quality of the ground air on large areas of the Earth's surface, in particular, tracking the average air quality over large cities with millions of inhabitants.

Goal: Searching for an answer to the question: "İs it possible to monitor the mortality in large urban centers by monitoring the air quality in them through satellites?"

2. Methodology

The ability to trace the impact of ground air pollution on mortality rates in large megacities with millions of inhabitants was surveyed for Ankara, the capital of the Republic of Turkey, a city with 4868418 inhabitants during the last census in 2011 [1]. Ankara is a city in the central part of the Anatolian plateau at an altitude of over 900 m. With a continental climate (average annual temperature 9,7 °C), with dry and hot summers, humid autumn and spring, cold winters [2].

Statistics on annual causes of death in Ankara were derived from Turkey's national statistics website [3] for the interval 2009 – 2016. The number of deaths is divided into 6 groups according to the cause of death: Diseases of the circulatory system; Neoplasms; Diseases of the respiratory system; Endocrine, nutritional and metabolic diseases; Diseases of the nervous system and the sense organs; External causes of injury and poisoning. The type of groups is consistent with the International Classification of Diseases, 10th Revision (ICD-10). The six groups cover a large proportion of deaths. For example, for Ankara, the six groups included 86% of the total 24335 deaths registered in 2017.

Satellite measurements are continuous measurements in the band under the satellite. The satellite flies in a polar orbit (over the two poles) at hundreds of kilometers, constantly shifting, covering the entire surface of the Earth. For example, the Terra satellite [5], on which board is mounted an instrument for ground-level atmosphere pollution monitoring (MOPITT), moves in a circular polar orbit at a height of 705 km, makes a tour around the Earth in 99 minutes, displaces to the west so that it passes over any point on the Earth's surface twice a day (Sun-synchronous polar orbit) at the same time of day and night, crossing the equator in the north direction at 10^h30^m local time (Daytime/Ascending) and in the south direction at 22^h30^m (Nighttime/Descending).

Due to the large height of the satellites above the ground surface, the measuring window of onboard measuring instruments covers a significant area of the Earth's surface, i.e. the measured values of the meteorological parameters and the ground pollution concentrations are averaged over the area. This effect which is hardly achievable from the surface measurement is appropriate in cases where the impact of average concentrations of pollutants on large areas, such as large cities, in particular, Ankara, is investigated.

Data on meteorological parameters and the concentrations of certain air pollutants for the years from 2009 to 2016 (for part of the data last year is 2015) were derived from a NASA site [6]. Altogether, 22 air quality parameters (ground level air pollutant concentrations and meteorological parameters) were included in the study:

A. *Concentrations of air pollutants*:

1. Ozone Total Column, DU (Dobson Units, Day Measurement (Daytime/Ascending), Night Measurement (Nighttime/Descending), instrument AIRS, Satellite EOS Aqua), 2 Parameters,
2. Methane Total Column, $kg.m^{-3}$ (Day Measurement (Daytime/Ascending), Night Measurement (Nighttime/Descending), instrument AIRS, Satellite EOS Aqua, 2 Parameters,
3. Black Carbon Surface Mass Concentration, $kg.m^{-3}$, MERRA-2 Model, 1 parameter,
4. Dust Surface Mass Concentration, $kg.m^{-3}$, MERRA-2 Model, 1 parameter,
5. Dust Surface Mass Concentration - PM 2.5 (Particulate matter with aerodynamic diameter 2,5 micrometers), $kg.m^{-3}$, MERRA-2 Model, 1 parameter,
6. SO4 Surface Mass Concentration, $kg.m^{-3}$, MERRA-2 Model, 1 parameter,
7. CO Surface Concentration, ppbv, MERRA-2 Model, 1 parameter,
8. NO2 Tropospheric Column (30% Cloud Screened), Number of $molecules.cm^{-1}$, OMI/Aura model, 1 parameter,
9. UV Aerosol Index, TOMS & OMI /Aura satellite, dimensionless, 1 parameter, characterizes the concentration of solid aerosols in the air (particulate matter and soot), calculated by spectral data for the absorption of UV radiation from solid particles into the air.

B. *Meteorological parameters*:

10. Surface pressure (2D), hPa, MERRA-2 Model, 1 parameter,
11. Downward longwave radiation flux, $W.m^{-2}$, GLDAS Model, 1 parameter,

12. Downward shortwave radiation flux, $W.m^{-2}$, GLDAS Model, 1 parameter,

13. Surface Temperature, K (Kelvin, Day Measurement (Daytime/Ascending), Night Measurement (Nighttime/Descending), instrument AIRS, Satellite EOS Aqua, 2 Parameters,

14. Air temperature at the surface, K (Kelvin, Day Measurement (Daytime/Ascending), Night Measurement (Nighttime/Descending), instrument AIRS, Satellite EOS Aqua), 2 parameters,

15. Relative Humidity at Surface,% (Kelvin, Day Measurement (Daytime/Ascending), instrument AIRS, Satellite EOS Aqua), 1 parameter,

16. Surface wind speed, $m.s^{-1}$, MERRA-2 Model, 1 parameter,

17. Cloud Fraction, ratio (Day Measurement (Daytime/Ascending), Night Measurement (Nighttime/Descending), instrument AIRS, Satellite EOS Aqua), 2 parameters.

The data used from NASA are in the form of daily and monthly values obtained as a result of satellite observations, ground observations and numerical models developed on their basis. They were averaged for the Ankara area (in a rectangle between the parallels 39,86°N and 40,04°N and the meridians 32,74°E and 32,96°E), and the data obtained in consecutive annual averages for the years 2009-2016.

A Causal relationship between mortality and influencing factors

The average annual number of deaths in Ankara on the one hand and the yearly averaged quality parameters of the air over Ankara, on the other hand, were analyzed by the statistical method of correlation analysis. The method produces a quantitative expression (*correlation coefficient*) of the degree of consistency in the changes of the two datasets. The more coherent are the changes, the greater is the probability of a causal relationship between air quality and the number of deaths, the likelihood the air pollution being among the causes of death in Ankara. The correlation method is applicable to the cases of linear dependence between the consistently changing datasets. In the case of the absence of consistency between the two series, the correlation coefficient is zero. Coherence can be expressed both in a coordinated increase and/or decrease of the two series (positive correlation) and in a concerted increase of one of the two, combined with a decrease of the other and vice versa (negative, reverse correlation). When there is complete consistency in changing the two sets of numerical values, the correlation coefficient is 1,000 for a positive correlation or -1,000 for a negative correlation. If the two sets of data are strongly correlated (the correlation coefficient is close to 1,000 of absolute value), the more likely a causal relationship between them is to exist. Complex processes such as illnesses are due to a multitude of causes, where the polluted air is just one of the possible. Having a strong correlation between the number of deaths from a given disease and the concentration of one of the pollutants does not mean that this pollutant is the only cause of the deaths from the disease but only that the pollutant is among the causes of death from that disease and there is a linear relationship between the number of deaths and the pollutant's concentration. In the work, only dependencies are suggested, which suggests a strong positive causal relationship between the concentration of a given air pollutant over Ankara and the number of deaths in Ankara. The existence of a strong positive causal relationship was assumed at the correlation coefficient values above 0,9.

The statistical significance level, which characterizes the availability of the correlation dependence, was also determined. It shows the probability of the established correlation to be due to an accidental coincidence of circumstances. The smaller is this probability, the more reliable is the correlation between two changing datasets, i. e. the more likely there is a causal relationship between the number of deaths and the concentration of the pollutant. In the study, correlations with a statistical significance of no more than 0,05 were considered statistically significant. I.e. the combination of a correlation coefficient greater than 0,9 with a significance level of less than 0,05 was used as the criterion for the causal relationship between the number of deaths and the concentration of a given pollutant.

Assessing the risk of death due to air pollution

Based on the above-mentioned criterion, for the cases where a cause and effect relationship was assumed between the number of deaths and the concentration of a given pollutant, the risk of death from the pollutant was assessed. A high correlation coefficient means a linear relationship between the number of deaths and the concentration of a given pollutant. A linear dependence was modelled with a linear regression model – a linear function between the cause parameter (independent variable) and the number of deaths in Ankara (dependent variable).

An independent variable in the regression models used was the difference between the annual concentration of the pollutant and the minimum among annual concentrations.

The regression models used had the general form:

Annual number of deaths = *Intercept* + $k * (C - C_{\min})$,

where k is the coefficient of the independent variable, the annual concentration of the respective pollutant is denoted by C, and Cmin is the minimum annual concentration for the studied interval. If the minimum value of the independent variable in the regression model is zero, the intercept is the number of deaths that are independent of the cause included in the regression model (through the independent variable). Therefore, in the regression models, the independent variables were chosen to be the differences in the concentrations of pollutants with their minimum value. In this case, the intercept in the regression model is the number of deaths unexplained by the independent variable in the regression model, for example, due to genetic, physiological, and other causes. Figure 1 shows the regression model of the dependence between the number of deaths in Ankara and the average annual density of methane molecules in the air up to the upper boundary of the stratosphere (a "total column", measured by a satellite, hereinafter referred to as "annual methane content").

The *determination coefficient* R^2 determines the quality of the model, i.e. the extent to which the change in annual methane content explains the change in the annual number of deaths in Ankara as assessed by the regression model. The determination coefficient reaches its maximum value of 1,000 for the discussed regression model when the change in annual deaths is explained only by the change in the annual methane content in the air over Ankara (then the experimental points lie on the regression line).

The product between the value of the independent variable (the pollutant concentration) in the model and its coefficient determines the contribution of the pollutant to the number of deaths, assessed by the model. The contribution of the pollutant was calculated by the average of its respective independent variable – the average of the above-mentioned differences in the annual pollutant concentration with its minimum value for the years surveyed.

The total contribution of all causes to the number of deaths was calculated as the sum of the contribution of the pollutant and the intercept in the model.

The risk of death for Ankara residents as a result of the impact of the given pollutant on the death from given group of diseases was calculated as the ratio (between 0 and 100%) of the contribution of the pollutant to the total contribution of all causes, assessed by the model.

3. Results

Statistically significant correlation coefficients of the mortality in Ankara with air quality parameters over the city measured by satellites were found for four out of six groups of causes of death – respiratory diseases, cardiovascular diseases, neoplasms, and diseases of the nervous system and sensory organs.

The change in mortality from respiratory diseases in Ankara closely follows the change in atmospheric pressure over the studied interval of years (correlation coefficient +0,966, significance level 0,001).

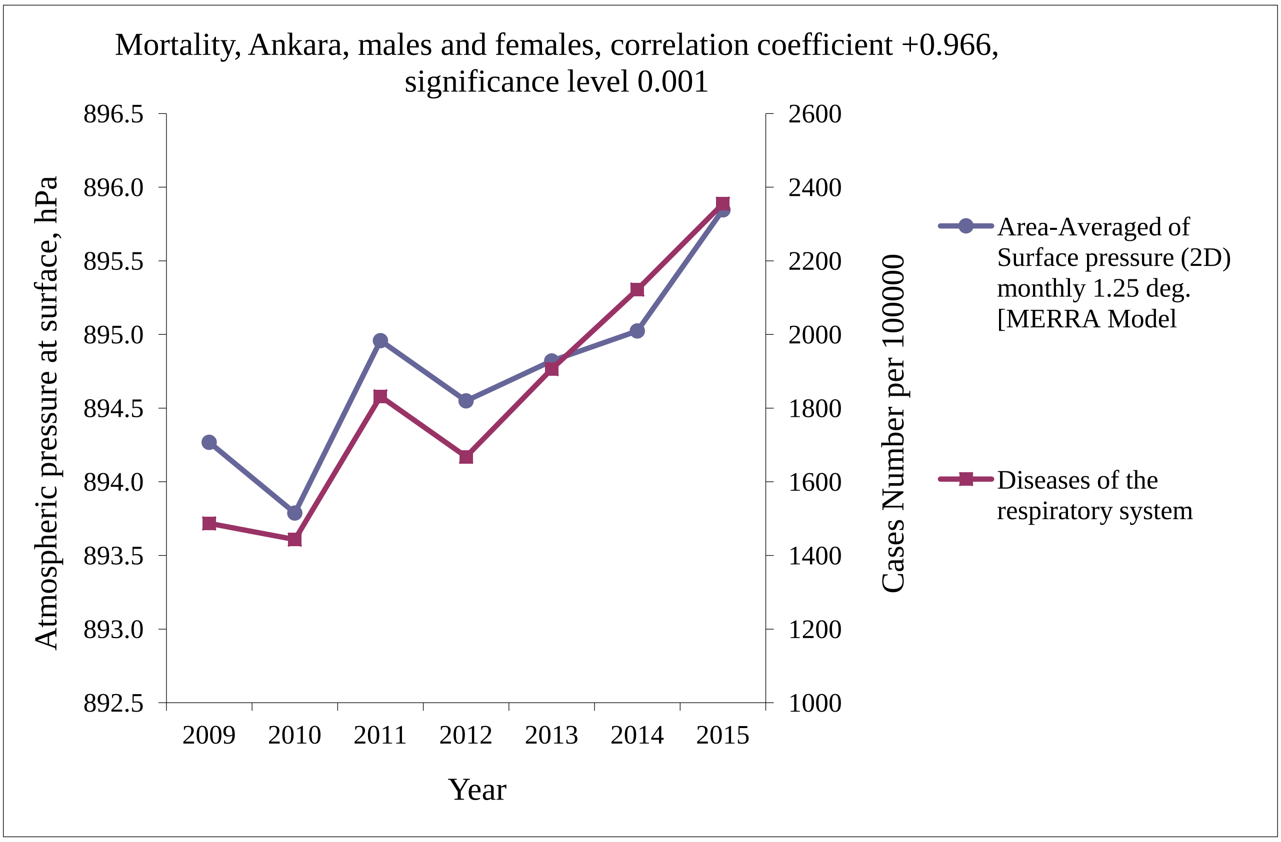

Figure 1. There is a high positive correlation between atmospheric pressure changes over the years of the study and the number of deaths from respiratory diseases in Ankara.

The high atmospheric pressure is associated with weather conditions favouring the accumulation of air pollutants at the ground surface – quiet time (no horizontal air pollution dispersion) and increased resistance to vertical movements (no vertical air pollution dispersion). The probable cause for a positive causal relationship between the number of deaths from respiratory diseases in Ankara with atmospheric pressure is that during the years with higher atmospheric pressure, more frequent conditions are created to accumulate near the ground surface of air pollutants emitted by traffic, industry and domestic heating.

The study showed that the air pollutant, whose concentration is most closely correlated with atmospheric pressure and mortality in Ankara, is methane. The correlation coefficient of methane concentration with atmospheric pressure is +0,970, with a significance level of 0,001 and the correlation coefficient of methane concentration with respiratory disease mortality in Ankara is +0,938, with a significance level of 0,01.

Figure 2 shows the dependence of the number of deaths from respiratory diseases in Ankara on methane air pollution over the city for the years of the study – the regression model and analytical form.

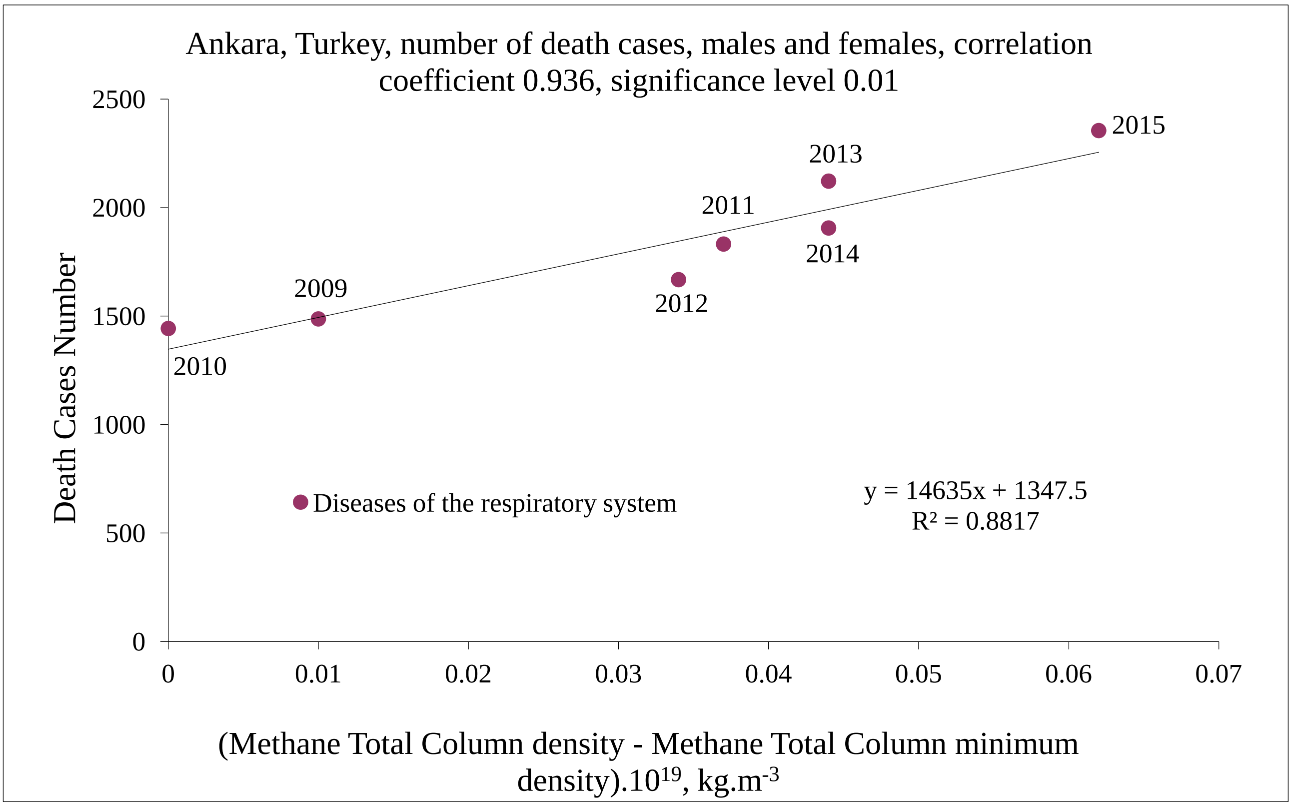

Figure 2. Regression model (line and mathematical expression) of the dependence between the number (y) of respiratory disease deaths in Ankara and the methane content (x) in the air. A continuous straight line denotes the regression model in which an independent variable is a difference between the annual methane content in the air and the smallest of these values.

The risk of death from respiratory diseases in Ankara related to the methane content in the air was calculated as described above using the coefficient (14635) and the intercept (1347,5) in the model for the mean value of the independent variable (0,033). The risk assessment obtained is 26%, i.e. as a result of air pollution with methane, the probability that Ankara's average citizen to die from respiratory illnesses has increased by 26%.

The average annual number of respiratory diseases deaths in Ankara for the study interval years is 1897, i.e. if the air over Ankara was free of methane pollution, this figure would have decreased by 501 cases (26%).

Methane concentration has a statistically significant correlation coefficient also with the mortality from neoplasms (0,768, statistically significant for level 0,05), cardiovascular diseases (0,861, statistically significant for level 0,05), neoplasms (0,772, statistically significant for level 0,05), and diseases of the nervous system and sensory organs (0,827, statistically significant for level 0,05).

The change in methane content in the air over Ankara during the year, calculated as average monthly values over the survey years, is shown in Figure 3. Methane content in the air over Ankara has two maximums in the year – the major in December and the second in August-September.

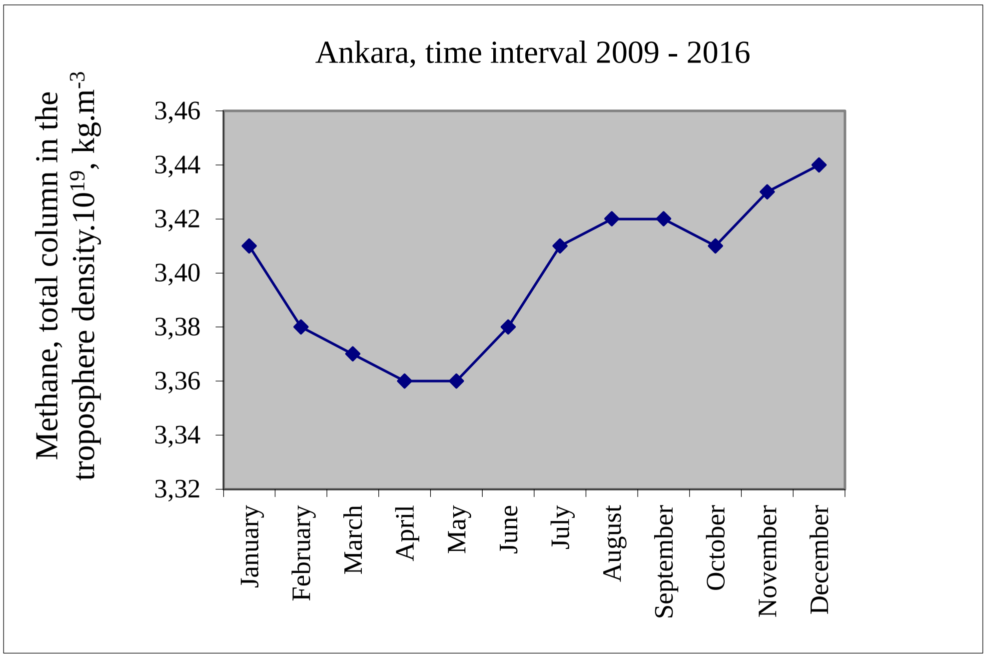

Figure 3. The annual rate of methane content in the air over Ankara averaged over the survey years.

The study revealed that there is a positive causal relationship between the UV Aerosol Index, which characterizes the content of solid aerosols (particulate matter) in the air above the city and the number of cardiovascular deaths in Ankara. The correlation coefficient of this dependence is +0,941 the significance level is 0,001. The regression model of the dependence is shown in Figure 4.

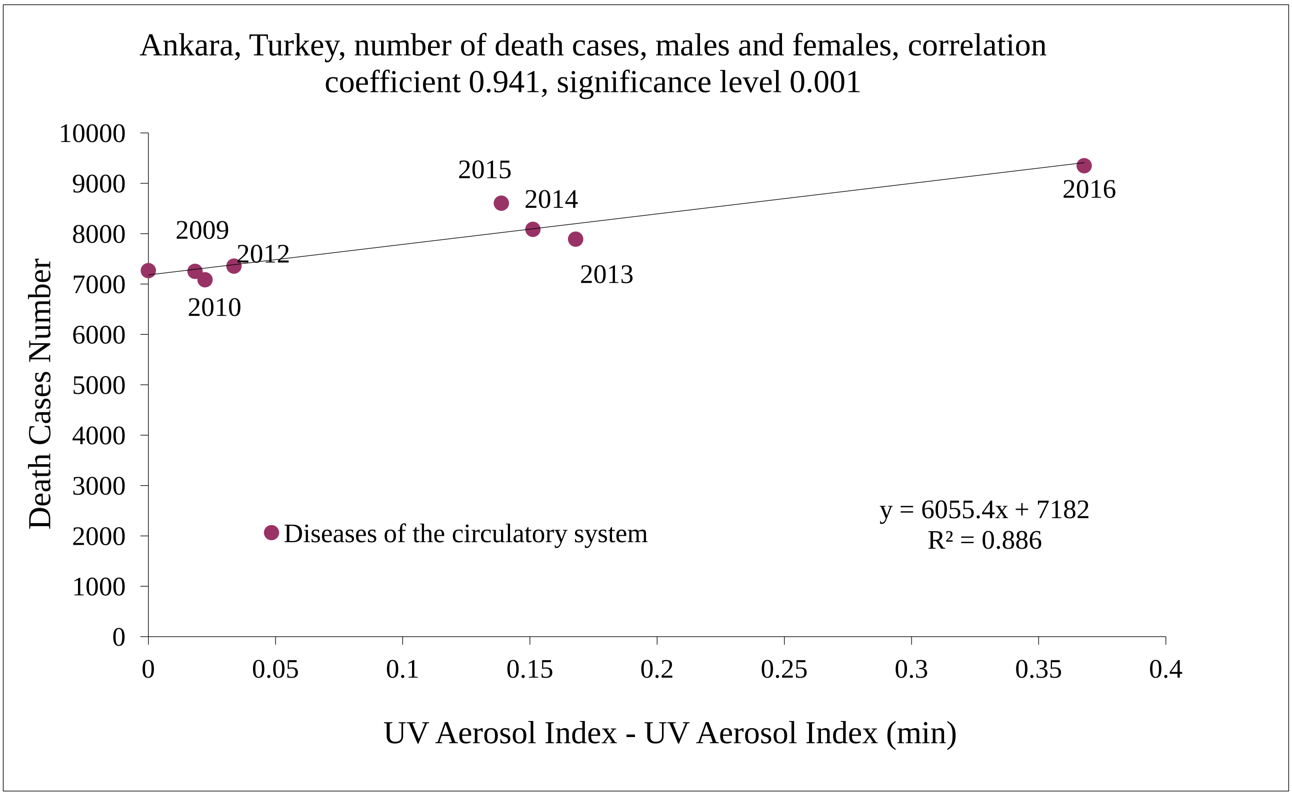

Figure 4. A regression model of the dependence between the number (y) of cardiovascular disease deaths in Ankara and the content (x) of solid aerosols. A continuous straight line designates the regression model in which an independent variable is a difference between the annual values of the UV Aerosol Index and the smallest of these values.

Based on the regression model, an increase (9%) in risk of death from cardiovascular diseases for the average citizen of Ankara due to air pollution with solid aerosols was calculated. An annual average of 7863 deaths from cardiovascular disease was recorded in Ankara. I.e. if the air over Ankara was free from solid aerosols, the number of death from cardiovascular diseases would decrease by 681 cases (9%). The study revealed that the highest concentration of solid aerosols in the air over Ankara is in the winter months from November to January.

The UV Aerosol Index is correlated with diseases of the respiratory system (correlation coefficient 0,788, significance level 0,05) and Diseases of the nervous system and the sense organs (correlation coefficient 0,761, significance level 0,05).

4. Conclusions

The study uses data from remote sensing from space and mortality statistics to reveal some ecological and toxicological problems of a big city, in this case, of Ankara.

It turned out that the air pollutant, whose concentration correlates most with atmospheric pressure and the number of deaths from respiratory diseases in Ankara, is methane. The pollution increases the risk of mortality from respiratory diseases with 26% (501 more death cases annually).

The air pollutant, whose concentration correlates most with the number of death cases from cardiovascular diseases in Ankara, are solid aerosols (dust, soot), which increases the risk of mortality from cardiovascular diseases with 9% (681 more death cases annually).

Not only the sensing is remote in the study – the authors are not Turkish citizens and they have never visited the area of the study (yet). I.e. the study is an example of the opportunities for environmental (and toxicological) research at any point in the world provided by modern technology.

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