Article

Estimation of Particulate Matter Impact on Human Health within the Urban Environment of Athens City, Greece

Konstantinos P. Moustris [1*], Kleopatra Ntourou [1] and Panagiotis T. Nastos [2]

[1] Laboratory of Fluid Mechanics, Mechanical Engineering Department, Piraeus University of Applied Sciences, 250 Thivon and P. Ralli Str., GR-12244 Athens, Greece; kntourou@puas.gr
[2] Laboratory of Climatology and Atmospheric Environment, Faculty of Geology and Geoenvironment, University of Athens, Panepistimiopolis Camp, GR-15784 Athens, Greece; nastos@geol.uoa.gr
[*] Corresponding Author: kmoustris@puas.gr

Abstract: The main objective of this work is the assessment of the annual number of hospital admissions for respiratory disease (HARD) due to the exposure to in-healable particulate matter (PM_{10}), within the greater Athens area (GAA), Greece. Towards this aim, the time series of the particulate matter with aerodynamic diameter less than 10μm (PM_{10}) recorded in six monitoring stations located in the GAA, for a 13-year period 2001-2013, is used. Initially, a descriptive statistical treatment of PM_{10} concentrations took place. Furthermore, the AirQ2.2.3 software developed by the WHO was used to evaluate adverse health effects by PM_{10} in the GAA during the examined period. The results show that, during the examined period PM_{10} concentrations present a significant decreasing trend. Also, the mean annual HARD cases per 100,000 inhabitants ranged between 20 (suburban location) and 40 (city centre location). Approximately 70% of the annual HARD cases are due to city centre residents. In all examined locations, a declining trend in the annual number of HARD cases is appeared. Moreover, a strong relation between the annual number of HARD cases and the annual number of days exceeding the European Union daily PM_{10} threshold value was found.

Keywords: particulate matter; AirQ model; hospital admission respiratory disease; Athens; Greece

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Introduction

Various epidemiological studies have shown the significant impacts of urban air pollution on human health. More concretely, several epidemiological studies have shown that the adverse health effects are related to both short and long term exposure to inhalable particulate matter [1-5].

During last decade, many researchers used the AirQ2.2.3 model, which a software developed by the World Health Organization (WHO) in order to investigate the influence of air pollution on public health and to estimate the adverse effects of air pollution on human health, especially in an urban populated environment. Shakour et al. [6] investigated the levels of particulate matter in selected sites in Cairo City, Egypt. The selected sites were chosen to present different activities at north and south areas of Cairo City. They applied the AirQ2.2.3 model in order to calculate the risk on human communities as result of particulate matter exposure. The output results showed that quantifying

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the impact of air pollution on the public's health has become an increasingly critical component in policy discussion.

Fattore et al. [7] applied AirQ2.2.3 model in two different small municipalities in a highly industrialized of Northern Italy in order to investigate the influence of particulate matter, ozone and nitrogen dioxide exposure on human health. According to their results AirQ2.2.3 model seems to be an effectively tool for such researches, helpful in decision-making.

Goudarzi et al. [8] used AirQ2.2.3 model to evaluate adverse health effects caused by nitrogen dioxide exposure in Ahvaz city, Iran during 2009. They found that approximately 3% of total cardiovascular mortality, acute myocardial infarction, and hospital admission for chronic obstructive pulmonary disease happened when the nitrogen dioxide concentrations was more than 20 $\mu g/m^3$. Low percentage of the observed health endpoints was associated with low concentration of measured nitrogen dioxide.

Naddafi et al. [9] applied AirQ2.2.3 model in Tehran City, Iran in order to asses adverse health effects due to the exposure to particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Results indicated that the magnitude of the health impact which has been estimated underscores the need for urgent actions to reduce the health burden of air pollution.

Jeong [10] in order to estimate the short-term mortality impact of air pollution applied the approach suggested by the World Health Organization (WHO), using AirQ2.2.3 software. Daily concentrations of particulate matter, ozone, nitrogen dioxide and sulfur dioxide were used to assess human exposure and health effects, in terms of attributable proportion of the health outcome, annual number of excess cases of mortality for all causes, and cardiovascular and respiratory diseases. The results are also in line with those of other international studies that apply AirQ software.

Habeebullah [11] investigated the health impacts of atmospheric particles with aerodynamic diameter of 10 micron or less (PM_{10}) in Makkah city, Kingdom of Saudi Arabia. For this purpose, the AirQ2.2.3 software-model was applied. The results of the model were discussed and compared with several studies conducted in other countries around the world.

Moustris et al. [12] in their study applied the AirQ2.2.3 model in order to evaluate adverse health effects by PM_{10} pollution in the coastal city of Volos, Greece during a 5-year period (200-2011). The results of the current study indicated that when the mean annual PM_{10} concentration exceeds the corresponding European Union (EU) threshold value [13], the number of hospital admissions for respiratory disease (HARD) due to PM_{10} is increased by 25% on average. Also, an estimated increase of about 2.5% in HARD compared to the expected annual HARD cases for Volos. Furthermore, a strong correlation was found between the number of days exceeding the EU daily threshold concentration ($[PM_{10}] \geq 50\ \mu g/m^3$) [13] and the annual HARD cases.

Finally, Omidi et al. [14] assessed the health risks associated with nitrogen dioxide in the city of Kermanshah, the capital of Kermanshah province, Iran. According to the results of the specific work the number of cases of mortality and morbidity caused by exposure to nitrogen dioxide in order to be reduced several immediate steps should be taken by the government to control emissions from various sources, particularly car exhaust, to reduce the levels of nitrogen dioxide in the atmosphere.

In this study, an effort was made to assess the annual number of hospital admissions for respiratory disease (HARD) due to the exposure to inhalable particulate matter (PM_{10}), within the greater Athens area (GAA), Greece.

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Results and Discussion

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Initially, a statistical treatment of the mean daily concentrations of PM_{10} during the examined period 2001-2013 was carried out. Figure 1 depicts the variation of the mean annual PM_{10} concentrations of the six examined locations within the GAA during the time period 2001-2013.

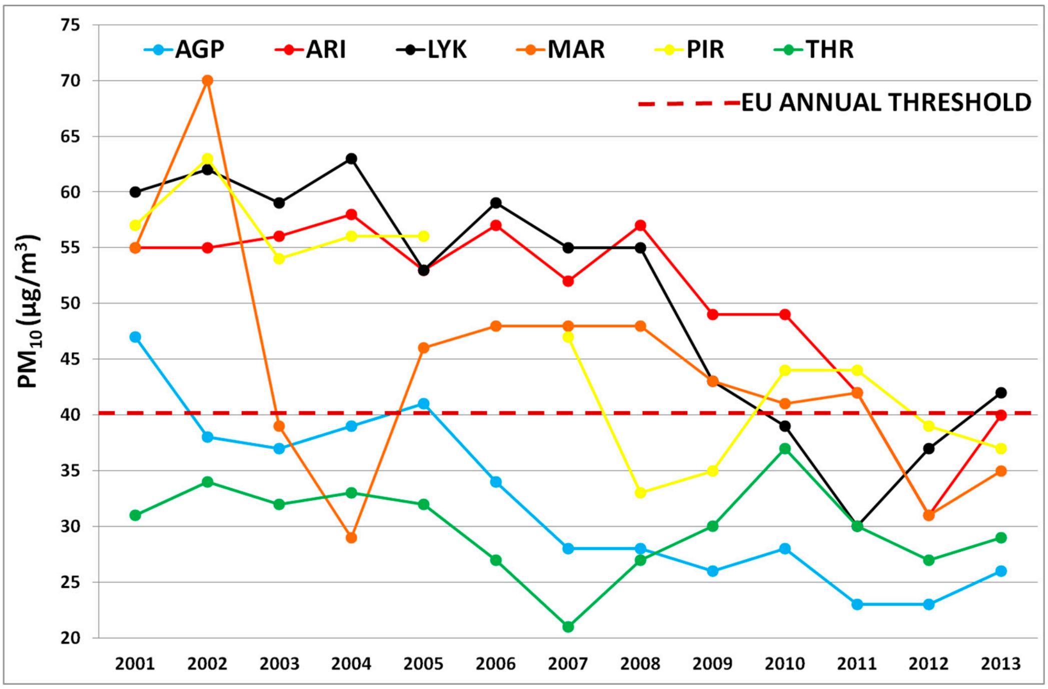


Figure 1: Mean annual PM_{10} concentrations within the GAA. Period 2001-2013

According to Figure 1, it seems that in all of the six examined locations, the variation of the mean annual PM_{10} concentrations presents a significant decreasing trend. It was found that the annual decreasing trend is lying between -0.3μg/m³ per year (THR) up to -2.4μg/m³ per year (LYK). Furthermore, until 2010 the locations of MAR, LYK ARI and PIR seems to have mean annual concentration of PM_{10} above the EU annual threshold ($[Pm_{10}]<40\mu g/m^3$), but during 2011-2013 all of the examined locations are below the aforementioned EU annual threshold.

Figure 2 shows the mean monthly PM_{10} concentrations within the GAA during period 2001-2013. It is obvious that in all cases there is a significant seasonality. In other words there is a significant variation of mean monthly PM_{10} concentrations during the changes of the seasons through the year. More specifically, during the cold period of the year (October-April) in the four of the examined locations (ARI, LYK, MAR and PIR) the mean monthly PM_{10} concentrations are higher than the corresponding during the warm period of the year (May-September). This is mainly due to the traffic and secondarily due to the use of oil and wood heading systems as well. Concerning the two remaining locations-stations (AGP and THR) the things look totally different. During the cold period of the year the mean monthly PM_{10} concentrations are less than the corresponding concentrations during the warm period of the year. In our opinion, this depicts that there are totally different sources of PM_{10} in the air between these locations. In the four of them (ARI, LYK, MAR and PIR) it seems that the PM10 sources are traffic and generally vehicles in contrast to the two other locations (AGP and THR) where it seems that nature is the most prevailing PM_{10} source. This is due to the different characteristics between these locations (see Table 2). AGP and THR are the only two stations characterized as suburban-background (S-BG) locations. All the other locations are characterized as traffic (T) or city center (CC) locations.

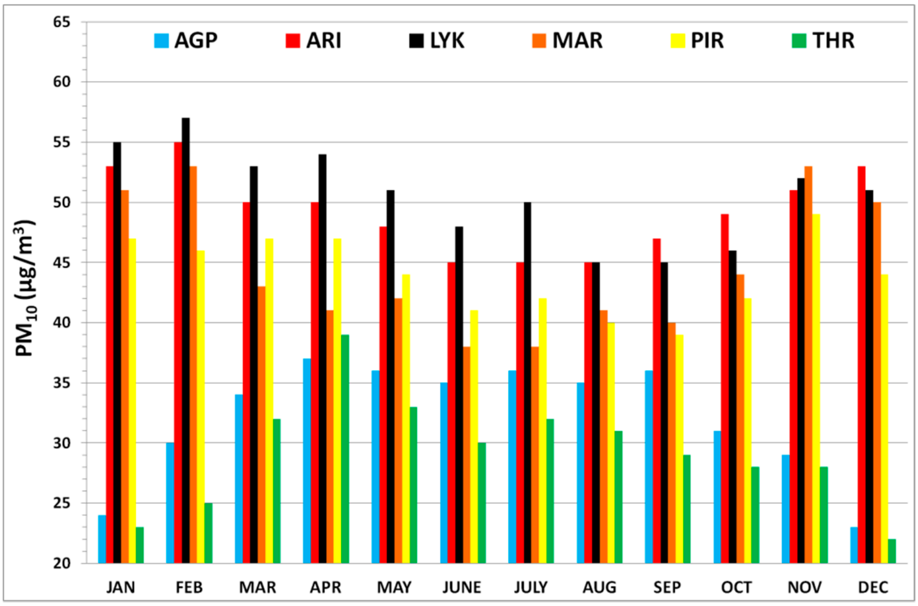
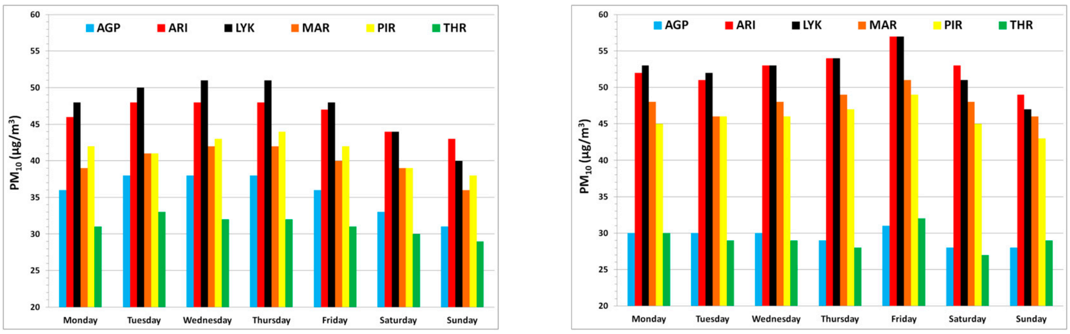


Figure 2: Mean monthly PM_{10} concentrations within the GAA. Period 2001-2013

In Figure 3 we can see the mean intra weekly variation of PM_{10} concentrations within the GAA during the warm period of the year (a) and during the cold period of the year (b) for the examined period 2001-2013. It is obvious that during the cold period of the year higher PM_{10} concentrations presented in contrast to the warm period of the year, except AGP and THR. But, in all stations-locations during weekend lower PM_{10} concentrations presented than the other working days of the week. This leads to the conclusion that traffic and generally vehicles are the mainly PM_{10} sources, because during weekends many people are away from the GAA for short vacations and the most of the other who remain within the GAA they don't use their vehicles.



(a) (b)

Figure 3: Mean intra weekly variation of PM_{10} concentrations within the GAA during the warm period of the year (a) and during the cold period of the year (b). Period 2001-2013

The EU Directive 2008/50/EC [13] on ambient air quality and cleaner air for Europe determines as a daily threshold concentration of PM_{10} the $50\mu g/m^3$. So, every day where the mean daily PM_{10} concentration is above $50\mu g/m^3$ is considered as an exceedance day. And if this happened, according to the EU Directive 2008/50/EC [13] the number of exceedance days must be less than 35 days per year (in other words less than 9.6% of the days of a year). For each station-location and for any of the years during the period 2001-2013 the annual number of the exceedances was calculated. Then and taking into account the completeness of each year (the number of days where records of PM_{10} concentrations were available) the annual percentage (%) of exceedances for each station-location was calculated. Figure 4 shows the annual rate (%) of PM_{10} concentration exceedances according to the EU daily threshold within the GAA during the period 2001-2013.

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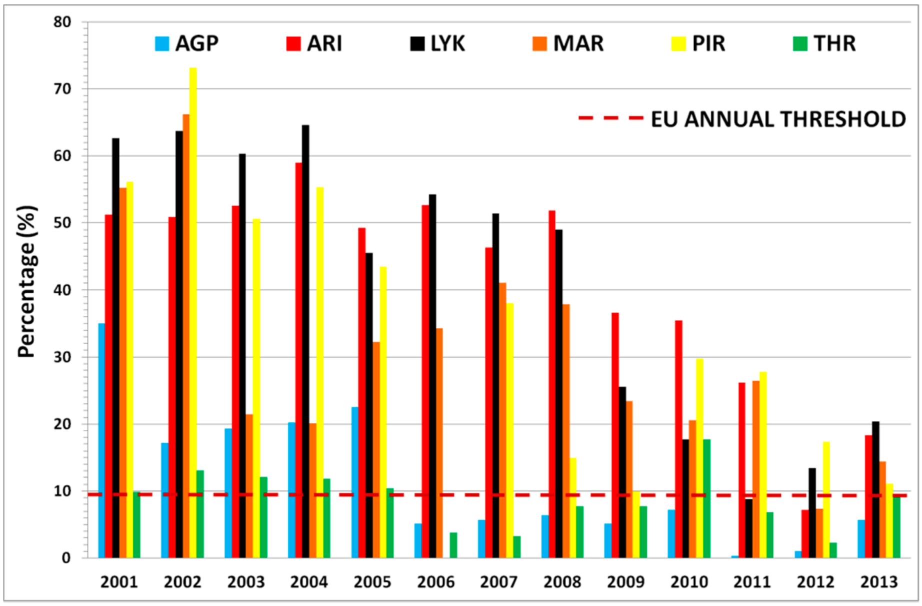
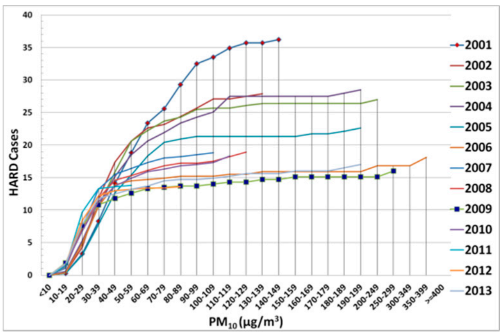


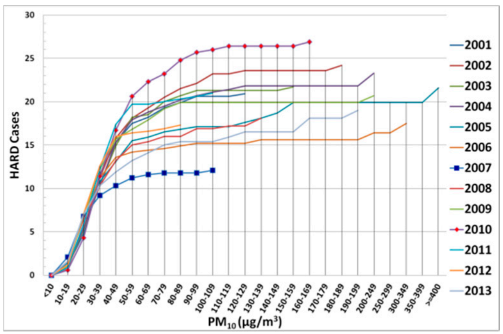
Figure 4: Annual rate (%) of PM_{10} concentration exceedances within the GAA. Period 2001-2013

According to Figure 4, it seems that at the four of the six examined locations-stations within the GAA (ARI, LYK, MAR and PIR) there is a significant higher annual number of exceedances, greater enough than the EU threshold of about 9.6%. But, through the years a significant decreasing trend of this rate is presented. Concerning the location AGP we can see that during the period 2001-2005 a higher rate of about 9.6% was presented too. But from 2006 up to 2013 the rate of the exceedance days is lower than the EU threshold of 9.6%. For the location THR it seems that there is not any problem concerning the annual number of exceedance days. For all years is lower than the EU corresponding threshold.

Subsequently, the AirQ2.2.3 model was applied for each one of the six examined stations-locations in order the annual number of HARD cases to be calculated. Figure 5 depicts the cumulative annual number of HARD cases due to PM_{10} per intervals of 10μg/m³ per 100,000 inhabitants within the GAA during the examined period 2001-2013. As it seems when the PM_{10} concentration exceeds the interval of 40-49μg/m³ then an exponential increase of the number of HARD cases occurs. This seems to be in full agreement with the daily PM10 threshold of 50μg/m³ established by the EU for the protection of public health.



AGP



THR

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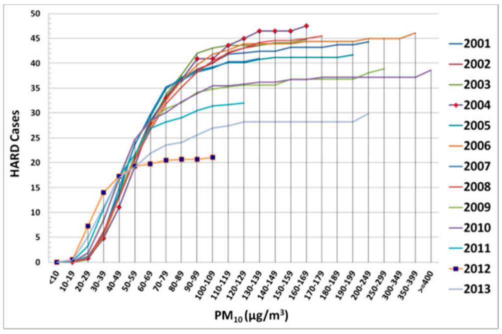
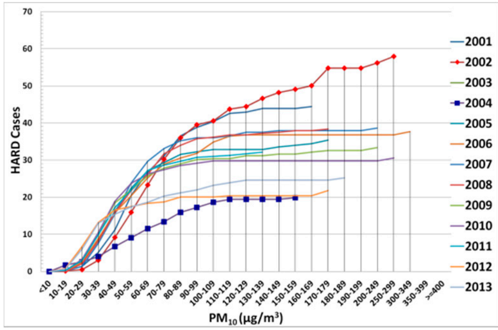
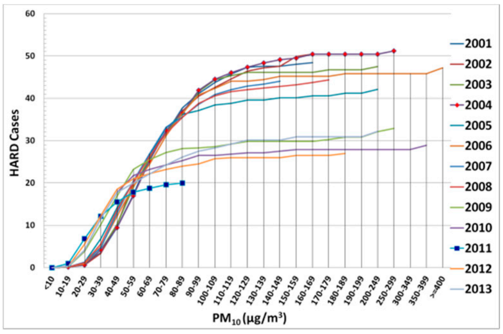


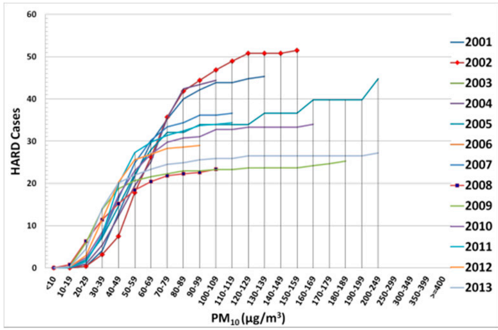
ARI



MAR



LYK



PIR

Figure 5: Cumulative annual number of HARD cases due to PM_{10} within the GAA. Period 2001-2013

Furthermore, the application of AirQ2.2.3 model at the six examined stations-locations showed that the centre of Athens (ARI) presents the highest annual number of HARD cases in relation to the whole population of each examined station-location.

Figure 6 shows the percentage (%) of total contribution of annual number of HARD cases during the period 2001-2013 in each studied location and according to the population of each location (see Table 2). Figure 6 depicts that in the city centre location ARI the total contribution of annual HARD cases, during the examined 13-year period, is equal to 69%. This may be attributed to the fact that city centre locations characterized by violations above the PM_{10} EU threshold value. The contribution of the CAA's port (PIR) is about 13%, then 6% is MAR and THR and finally about 3% is the contribution of AGP and LYK. This contribution is strongly associated with the local sources of PM_{10} in each examined location.

In order the annual number of HARD cases between the different locations within the GAA and for different populations to be comparable, the annual number of HARD cases was normalized per 100,000 inhabitants with the application of AirQ2.2.3 model. In Figure 7, the percentage (%) of the contribution of annual number of HARD cases during the period 2001-2013 in each studied location per 100,000 inhabitants is depicted. According to Figure 7, ARI (city center) and LYK presented the highest rate of about 21%. This indicates that the area of Lykovrissi (LYK) presents the same high values of HARD cases per year and per 100,000 inhabitants as the city's center ARI. Then, the port of Piraeus (PIR) presents a rate of about 19%. This is maybe due to the port activities through the year and especially during the summer time. Maroussi (MAR) presents a rate of about 17% and finally Thrakomakedones (THR) and Agia Paraskevi (AGP) present the lowest rate of about 11%.

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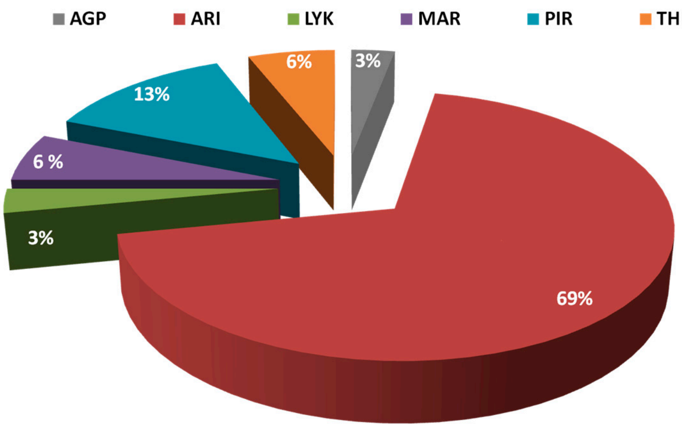

Figure 6: Percentage of total contribution of annual number of HARD cases during the period 2001-2013 in each studied location and according to the population of each location (see Table 2)

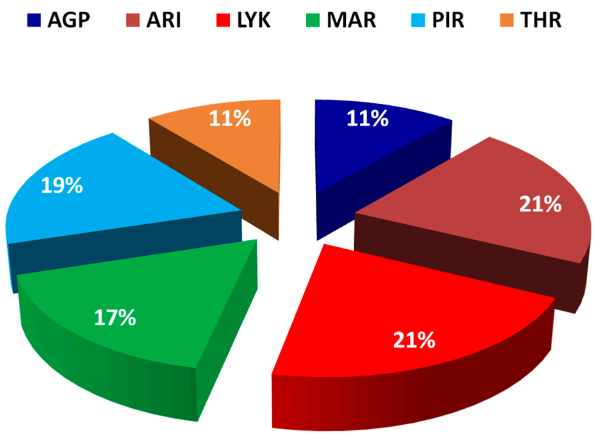

Figure 7: Percentage of total contribution of annual number of HARD cases during the period 2001-2013 in each studied location per 100,000 inhabitants

In general terms, it seems that the contribution of each location to the annual number of HARD cases per 100,000 inhabitants is different instead of taking into account the whole population of the location. The results of the application of AirQ2.2.3 model concerning this magnitude, for all studied locations and for the whole examined period 2001-2013 reveal that LYK, ARI, PIR and MAR are the worst areas presenting a number of mean annual HARD cases per 100,000 inhabitants 40≤HARD≤35. The areas of AGP and THR presenting a number of mean annual HARD cases per 100,000 inhabitants 22≤HARD≤20, respectively.

In order to provide quantitative relations for the temporal variability of the annual number of HARD cases per 100,000 inhabitants and the annual means of PM_{10} concentrations during the examined 13-year period, scatter diagrams were constructed (Figures 8a-8b). Figure 8a depicts that, by using the linear model, 91.2% of the variance (R^2=0.912) of annual values of HARD cases can be explained by the evolution of time. Moreover, for the mean annual PM_{10} concentrations, using the linear model, 90.1% of the variance (R^2=0.901) of means can be explained by the evolution of time (Figure 8b). According to the performed analysis, during the 13-year period started in 2001, strong decreasing trend patterns appear both annual HARD cases per 100,000 inhabitants (Figure 8a) and mean annual PM_{10} concentration values (Figure 8b) all over the GAA.

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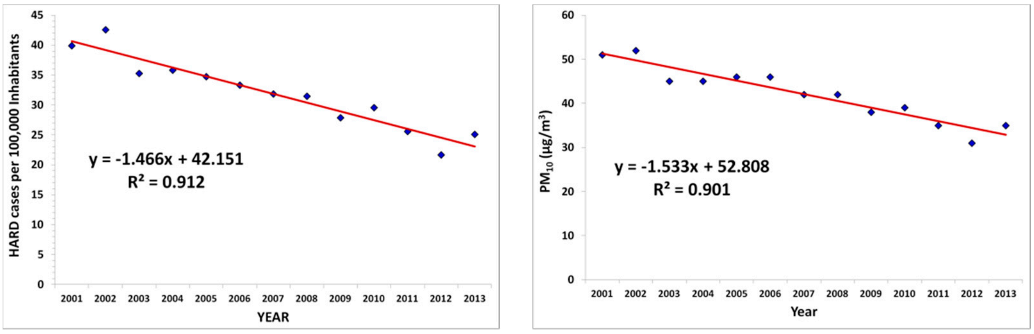

(a) (b)

Figure 8: Temporal variability of annual HARD cases per 100,000 inhabitants (a) and temporal variability of mean annual PM_{10} concentrations (b), during the period 2001-2013 within the GAA.

Figure 9 presents the spatial distribution of the mean annual HARD cases within the GAA in relation to the total population and the activities of each examined location. From Figure 9 is depicted that the centre of Athens (ARI) is the most populous and burdened area which is presenting a mean annual number of HARD cases from 60 up to 262 cases based always on the population of about 664,000 inhabitants. Secondary, the port of the GAA (PIR) follows due to shipping activities presenting a mean annual number of HARD cases from 30 up to 60 cases. Finally, all the other locations present a similar low intensity pattern from 0 up to 30 HARD cases per year, based always on their population (see Table 2).

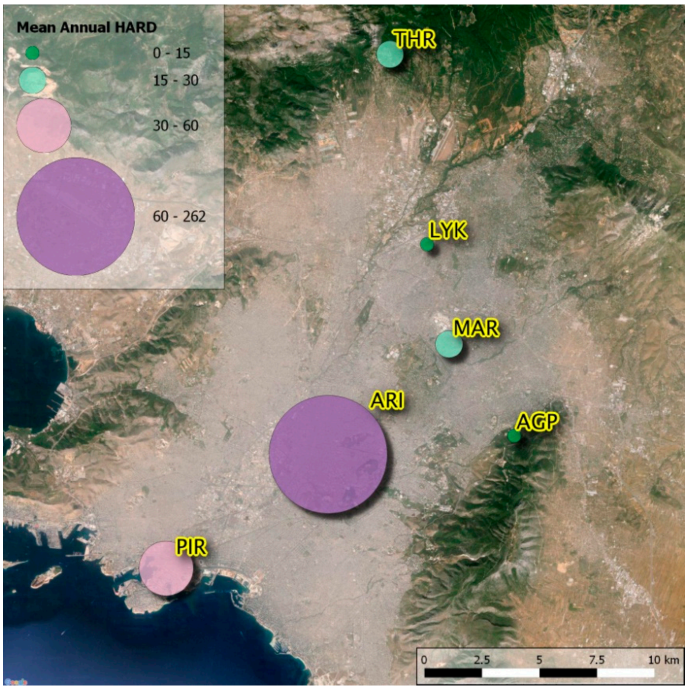

Figure 9: Spatial distribution of mean annual HARD cases during the period 2001-2013, based on the population of each location.

Finally, in order to provide a quantitative relation between the annual number of HARD cases and the annual number of days where PM_{10} concentration values exceed the European Council (EC) threshold of 50μg/m³ [13] was investigated. Figure 10 indicates that by using the exponential fitting model, 77.7% (R^2=0.777) of the variance of the annual HARD cases can be associated with the variations of the annual numbers of days with excesses. Furthermore, when the number of exceedance days is greater than or equal to 35, then the number of HARD cases due to PM_{10} exposure increases exponentially. This seems to be in full agreement with the limit number of 35 exceedance days per year which has been established by the EU for the protection of public health.

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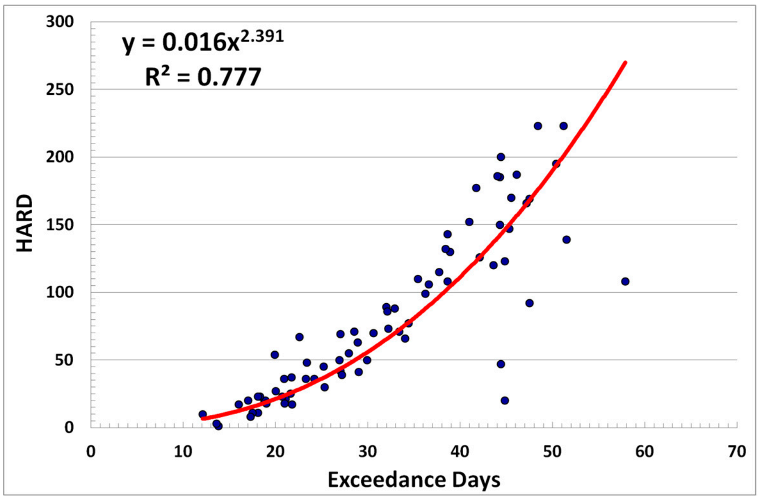

Figure 10: Scatter plot between annual HARD cases versus annual number of exceedance days ([PM_{10}]≥50μg/m^3) in the GAA during the period 2001-2013. The solid line represents the exponential fitting model.

Table 1 presents a comparative analysis of HARD cases per 100,000 inhabitants due to PM_{10} exposure for different sites worldwide. As it seems from other works worldwide and the present work, only Volos City, Greece and Suwon City, Seoul, South Korea can be compared with the six examined locations within the GAA and in general within Athens City, the Capital City of Greece. In all these cities, the mean annual PM10 concentration is around 30μg/m^3 to 50μg/m^3 and the annual number of HARD cases per 100,000 inhabitants is laying around 20 to 40 cases. Then, the Capital City of Tehran, Iran is following with a mean annual PM10 concentration of about 90.6μg/m^3 and a mean annual number of HARD cases around to 77 cases per year. For the Holy City of Makkah, Saudi Arabia and the Capital City of Cairo, Egypt we can see that the situation concerning the HARD cases per year due to PM10 exposure is dramatic. These two cities present a huge number of HARD cases per year as well as a huge mean annual PM_{10} concentration.

Table 1: Comparative analysis of HARD cases per 100,000 inhabitants due to PM_{10} exposure for different sites worldwide

Location	Period	Mean annual PM_{10} concentration (μg/m^3)	Number of HARD cases per 100,000 inhabitants	RR	Reference
Volos, Greece	2007-2011	41.2	32	1.008	[12]
Suwon City, Seoul, South Korea	2011	52.0	39	1.008	[10]
Tehran, Iran	2010	90.6	77	1.008	[9]
Holy City of Makkah, Saudi Arabia	2012-2013	195.5	2,504	1.096	[11]
South Shoubra El-Kheima, Cairo, Egypt	2008-2009	267.0	4,919	1.274	[6]
North Shoubra El-Kheima, Cairo, Egypt	2008-2009	306.0	10,941	1.138	[6]
North Helwan, Cairo, Egypt	2008-2009	382.0	5,002	1.290	[6]
South Helwan, Cairo, Egypt	2008-2009	441.0	4,053	1.377	[6]
Aristotelous (Athens city	2001-2013	50.1	40	1.008	Present

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center), Greece					work
Lykovrissi, Greece	2001-2013	50.3	40	1.008	Present work
Maroussi, Greece	2001-2013	44.5	35	1.008	Present work
Piraeus (port), Greece	2001-2013	44.2	36	1.008	Present work
Agia Paraskevi, Greece	2001-2013	32.1	21	1.008	Present work
Thrakomakedones, Greece	2001-2013	30.0	20	1.008	Present work

Materials and Methods

The GAA, like most metropolitan areas in the world, faces severe air pollution problems due to high population density and the accumulation of major economic activities in this region. The contribution of the intense sunshine to the high levels of photochemical air pollution, especially during summer months, is significant. The air pollution problems are often exacerbated by factors that favor the accumulation of air pollutants over the city, such as topography (basin surrounded by mountains), narrow and deep street canyons and adverse meteorological conditions, such as temperature inversions, low wind speed, high air temperature, extensive periods of dryness [15-16]. For the estimation of HARD cases mean daily concentrations of PM_{10} used in this research recorded by the network of the Greek Ministry of Environment and Energy (GMEE). In the current work the mean daily PM_{10} concentration values in six of the GMEE's network stations are examined during the 13-year period 2001-2013. Monitoring stations are classified as centre city (CC) or suburban (S) ones, by their location, and also as traffic (T) or back-ground (BG) ones, by their categorization (Table 2).

Table 2: List of locations-stations and related information

Station	Abbreviated station name	Area	Population	Longitude	Latitude
Agia Paraskevi	AGP	S-BG	60,000	37° 59' 42''	23° 49' 10''
Lykovrissi	LYK	S-T	31,000	38° 04' 11''	23° 46' 35''
Maroussi	MAR	S-T	73,000	38° 01' 51''	23° 47' 14''
Thrakomakedones	THR	S-BG	107,000	38° 08' 37''	23° 45' 29''
Piraeus	PIR	CC-T	164,000	37° 56' 36''	23° 38' 51''
Aristotelous	ARI	CC-T	664,000	37° 59' 16''	23° 43' 39''

In order to estimate the annual number of HARD cases within the GAA, the Air Quality Health Impact Assessment Tool (AirQ2.2.3) was applied. The AirQ2.2.3 model is a specialized software that enables the user to assess the potential impact of exposure to a given air pollutant on human health in a defined urban area during a certain time period. The model requires the following data [6-12, 14]:

I. The coordinates of the monitoring site.
II. The total exposed population.
III. The number of days in which the mean daily PM10 concentration falls within categories of intervals of 10 mg m-3 (e.g., 0-9, 10-19, 20-29, etc.).
IV. The annual and seasonal arithmetic mean of mean daily values.
V. The annual 98th percentile of mean daily values.
VI. The annual and seasonal maximum daily values.
VII. The relative risk (RR).

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The AirQ2.2.3 model can be used to estimate the cumulative number of cases per 100,000 persons for each concentration range, the associated relative risk, and the number of HARD cases [6-12, 14].

Conclusions

The main objective of this study was the estimation of annual number of HARD cases that attributed to PM10 exposure in the greater Athens area and performed by the use of AirQ2.2.3 model. Results showed that there is a strong relationship between the HARD cases and PM10 exposure levels. Also, a decreasing trend during the examined 13-year period concerning the annual number of HARD cases and the mean annual PM_{10} concentration values within the GAA simultaneously was found.
The GAA seems to be in a better shape in contrast with other metropolitan cities such the Holy City of Makkah, Saudi Arabia and the City of Cairo, Egypt and despite the fact that several times per year the GAA receives large amounts of particulate matter from Africa, influenced by the phenomenon of Sahara Dust Event [17-18]. During the last years it is obvious that the air quality (concerning the PM_{10}) gets better and better something which is very good for public health. According to our knowledge, this is a result of a number of different measures and actions that have been taken by the state such as:

1. Since 2000 began the operation of GAA's metro (underground) with two new lines, servicing about 1,000,000 per day. This means that a mean number of about 250,000 vehicles are not moving anymore within the GAA reducing by this way the levels of air pollution all around the GAA.
2. Since 2001 began the operation of GAA new International Airport. In contrast with the new airport, the old one was very close to the city and close to the sea. So, the prevailing south winds transfer pollutants within the GAA which is surrounded by high mountains from west to the east.
3. Since 2002 began the operation of the new highway through the GAA called Attiki Odos. This highway is placed from east to west connecting the most populous locations of the GAA with the new International Airport. Moreover, because of high speed developed by the cars, burning becomes better and better resulting less fuel needs and lower emissions.
4. Since 2002 began the operation of Bus Lanes (BL) within the GAA. These BL are exclusively for the use only by buses. As a result of this the mean speed of buses increased significantly. So, fewer busses are able to cover the same distance in less time than before. By this way, there is lower pollutants emission and also buses become more attractive for public, thus reducing the number of private vehicles in the streets.
5. Finally, the economic crisis since 2008 prevents people to use their cars and oil for heating reducing oil consumption and pollutants emissions as well.

Further investigation is required in order the adverse health effects on public human health to be estimated for other pollutants such as nitrogen dioxide, sulfur dioxide, ozone, carbon monoxide, volatile hydrocarbons, etc.

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