ACEPT-AIR

LIFE+ 09 ENV/GR/000289

Action 2

Deliverable D6.

TITLE: PM_{10} and $PM_{2.5}$ Concentration Databases for the three urban areas AMA, TMA and VGA

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Coordinated by:

Aristotle University of Thessaloniki

D6. PM_{10} and $PM_{2.5}$ Concentration Databases for the three urban areas AMA, TMA and VGA

EXECUTIVE SUMMARY

In the framework of the LIFE09 ENV/GR/000289 project "Development of a Cost Efficient Policy Tool for reduction of Particulate Matter in AIR (ACEPT-AIR)", a PM concentration database was constructed for three urban areas of Greece: the Athens Metropolitan Area (AMA), the Thessaloniki Metropolitan Area (TMA) and the Volos Grater Area (VGA). For AMA and TMA, data for more than one site are available (traffic sites, urban background sites and in some cases industrial sites).The database includes information for PM mass and chemical constituents' concentration measured at various sites inside the aforementioned areas during the period 2000-2010 (Historical Data), as well as data measured during 2011-2012 in the framework of the ACEPT-AIR project (LIFE Data).

This database is very useful because it does not only offer an easy access to the aforementioned data, but it can be used as a tool for studding the trend of PM mass and chemical constituents' concentration throughout the years as well. Those trends can be used to assess the effect of the environmental policy followed by the Government of Greece, as well as point out the need of establishing new measures. Studding those trends, a significant decrease of PM_{10} and $PM_{2.5}$concentration levels during the last two decades is apparent, particularly at traffic sites, as a result of pollution abatement measures including improvement regarding the age of the vehicle fleet and the corresponding engine technology, improvement of fuel quality, increased use of natural gas for space heating and energy production in industry, etc.

Results from the ACEPT-AIR campaigns, revealed that even though PM levels are significantly lower than the previous years, there are still several cases of exceedance of the EU limit values regarding PM. During the warm season of the sampling campaigns there were exceedances of the PM_{10} daily limit value set by Directive 2008/50/EC only in TMA urban traffic site with 13 out of 28 days exceeding the 24-hr limit value. Similarly, $PM_{2.5}$ levels during warm season were above the annual target value set by EU (25 μg m^{-3}) only in TMA/UT.

During cold season a significant increase in PM levels was observed. Exceedances of the PM_{10} 24-hr limit value were observed in all sites.The lowest concentration levels were measured at the background sites with only a small number of exceedances while the highest were observed at the more densely populated site of Nea Smyrni in Athens, and in Volos where PM_{10} concentrations were above the 50 μg m^{-3} limit value for 33% and 70% of the measurement days respectively. Mean cold season concentration in Volos was much higher than the annual limit value (74 μg m^{-3}).

$PM_{2.5}$ levels were significant as well, with mean cold season values close or higher than the annual target value of 25 μg m^{-3}.Yearly mean PM_{10} concentrations exceeded the annual limit value of the air quality Directive 2008/EC/50 (40 μg m^{-3}) at the traffic site in Thessaloniki and in Volos. Correspondingly, the yearly mean $PM_{2.5}$ concentrations exceeded the annual target value of 25μg m^{-3} at both urban background and traffic site in TMA.

ΠΕΡΙΛΗΨΗ

Στα πλαίσια του προγράμματος LIFE09 ENV/GR/000289 και για το έργο “Ανάπτυξη ενός Εργαλείου άσκησης αποτελεσματικών πολιτικών για τη μείωση των αιωρούμενων σωματιδίων στον αέρα (ACEPT-AIR)” δημιουργήθηκε από τους συνεργαζόμενους φορείς μία βάση δεδομένων συγκεντρώσεων αιωρούμενων σωματιδίων (ΑΣ) για τρεις αστικές περιοχές της Ελλάδας: την μητροπολιτική περιοχή της Αθήνας (ΜΠΑ), την μητροπολιτική περιοχή της Θεσσαλονίκης (ΜΠΘ) και την ευρύτερη περιοχή του Βόλου (ΕΠΒ). Για τις ΜΠΑ και ΜΠΘ υπάρχουν δεδομένα για περισσότερες της μίας τοποθεσίες/θέσεις δειγματοληψίας (θέσεις αυξημένης κίνησης οχημάτων, θέσεις αστικού υποβάθρου και σε ορισμένες περιπτώσεις βιομηχανικές θέσεις). Η βάση δεδομένων εμπεριέχει δεδομένα για τη συγκέντρωση μάζας και για τα χημικά συστατικά των ΑΣ για διάφορες θέσεις εντός των προαναφερθέντων περιοχών για τις περιόδους 2000-2010 (“Ιστορικά δεδομένα”), καθώς και τα δεδομένα που προέκυψαν από τις μετρήσεις που πραγματοποιήθηκαν στα πλαίσια του προγράμματος ACEPT-AIR την περίοδο 2011-2012 (Δεδομένα “LIFE”).

Η βάση δεδομένων αυτή, είναι ιδιαίτερα χρήσιμη, καθώς δεν προσφέρει μόνο εύκολη πρόσβαση στα προαναφερθέντα δεδομένα, αλλά μπορεί επίσης να χρησιμοποιηθεί ως ένα εργαλείο μελέτης της τάσης διακύμανσης που παρουσιάζουν χρονικά οι συγκεντρώσεις μάζας και χημικών συστατικών των ΑΣ. Η τάση διακύμανσης αυτή μπορεί να χρησιμοποιηθεί για να εκτιμηθεί η επίδραση των περιβαλλοντικών μέτρων που θεσπίστηκαν από την Ελληνική κυβέρνηση, καθώς και να διαπιστωθεί η ανάγκη θέσπισης νέων μέτρων. Η μελέτη αυτών των τάσεων φανερώνει μία σημαντική μείωση της συγκέντρωσης των $ΑΣ_{10}$ και $ΑΣ_{2.5}$ τις τελευταίες δύο δεκαετίες, κυρίως σε σταθμούς που εκπροσωπούν σημεία με υψηλή κίνηση οχημάτων, το οποίο έρχεται ως συνέπεια της εφαρμογής περιβαλλοντικών μέτρων καθώς και βελτιώσεων που περιλαμβάνουν τη μείωση της μέσης παλαιότητας του στόλου των οχημάτων και κατά συνέπεια της καλύτερης τεχνολογίας που τα συνοδεύει, την ποιότητα των καυσίμων, την αύξηση της χρήσης φυσικού αερίου για θέρμανση, παραγωγή ενέργειας, για βιομηχανικές εφαρμογές κτλ.

Τα δεδομένα από τις μετρήσεις που πραγματοποιήθηκαν στα πλαίσια του ACEPT-AIR, έδειξαν ότι αν και τα επίπεδα των ΑΣ είναι σημαντικά μειωμένα σε σχέση με τα προηγούμενα χρόνια, παρατηρούνται ακόμα αρκετές περιπτώσεις υπέρβασης των θεσπισμένων από την Ε.Ε. ορίων. Κατά την θερμή περίοδο δειγματοληψίας υπήρξαν υπερβάσεις του ημερήσιου ορίου για τα $ΑΣ_{10}$ σύμφωνα με την Οδηγία 2008/50/EC μόνο στον σταθμό κυκλοφορίας (urban traffic site, UT) της ΜΠΘ, σε 13 από τις 28 ημέρες δειγματοληψίας. Αντίστοιχα, στη συγκεκριμένη περιοχή η μέση συγκέντρωση των $ΑΣ_{2.5}$ για τη θερμή περίοδο ήταν υψηλότερη από την ετήσια τιμή στόχο που έχει τεθεί από την Ε.Ε. (25 μg m^{-3}).

Κατά την διάρκεια της ψυχρής περιόδου παρατηρήθηκε σημαντική αύξηση των επιπέδων των ΑΣ. Υπερβάσεις του ημερήσιου ορίου $ΑΣ_{10}$ παρατηρήθηκαν σε όλες τις περιοχές. Οι χαμηλότερες συγκεντρώσεις παρατηρήθηκαν στις θέσεις υποβάθρου, με πολύ μικρό αριθμό υπερβάσεων, ενώ οι υψηλότερες παρατηρήθηκαν στην πυκνοκατοικημένη περιοχή της Νέας Σμύρνης στην Αθήνα και στο Βόλο, με τις συγκεντρώσεις των $ΑΣ_{10}$ να είναι υψηλότερες από το ετήσιο όριο των 50 μg m^{-3} στο 33% και στο 70% των ημερών δειγματοληψίας αντίστοιχα. Η μέση συγκέντρωση των $ΑΣ_{10}$ στο Βόλο ήταν σημαντικά υψηλότερη από το ετήσιο όριο (74 μg m^{-3}). Τα επίπεδα των $ΑΣ_{2.5}$ ήταν επίσης υψηλά, με μέση συγκέντρωση την ψυχρή περίοδο κοντά ή μεγαλύτερη από την ετήσια τιμή στόχο των 25 μg m^{-3}. Οι μέσες ετήσιες συγκεντρώσεις $ΑΣ_{10}$ υπερέβαιναν το όριο της Οδηγίας 2008/EC/50 (40 μg m^{-3}) στη θέση κυκλοφορίας (UT) της Θεσσαλονίκης και στον Βόλο. Αντίστοιχα η μέση ετήσια συγκέντρωση των $ΑΣ_{2.5}$ ξεπερνούσε την τιμή στόχο των 25 μgm^{-3} τόσο στη θέση κυκλοφορίας όσο και σε αυτήν του αστικού υποβάθρου στην ΜΠΘ.

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1.INTRODUCTION

A mass concentration and chemical composition Database was constructed in the framework of the LIFE09 ENV/GR/000289 project "Development of A Cost Efficient Policy Tool for reduction of Particulate Matter in AIR (ACEPT-AIR)" for particle fractions PM_{10} and $PM_{2.5}$ at three urban areas of Greece: the Athens Metropolitan Area (AMA), the Thessaloniki Metropolitan Area (TMA) and the Volos Greater Area (VGA). These data were then used for the source apportionment of ambient PM_{10} and $PM_{2.5}$ using receptor models.The Database also incorporated relevant historical data for the three study areas since 1990.

This report presents a description of the PM_{10} and $PM_{2.5}$ Mass Concentration Databaseand summarizes the concentrations of ambient PM_{10} and $PM_{2.5}$ levels measured in AMA, TMA and VGA in the framework of the ACEPT-AIR project.

2. METHODOLOGY

2.1 Description of the ACEPT-AIR project sampling sites

The ACEPT-AIR project was concurrently carried out at 2 sites in the **A**thens **M**etropolitan**A**rea, AMA (Figure 1), at two sites in the **T**hessaloniki **M**etropolitan **A**rea, TMA (Figure 2), and at one site in the **V**olos **G**reater **A**rea, VGA (Figure 3).

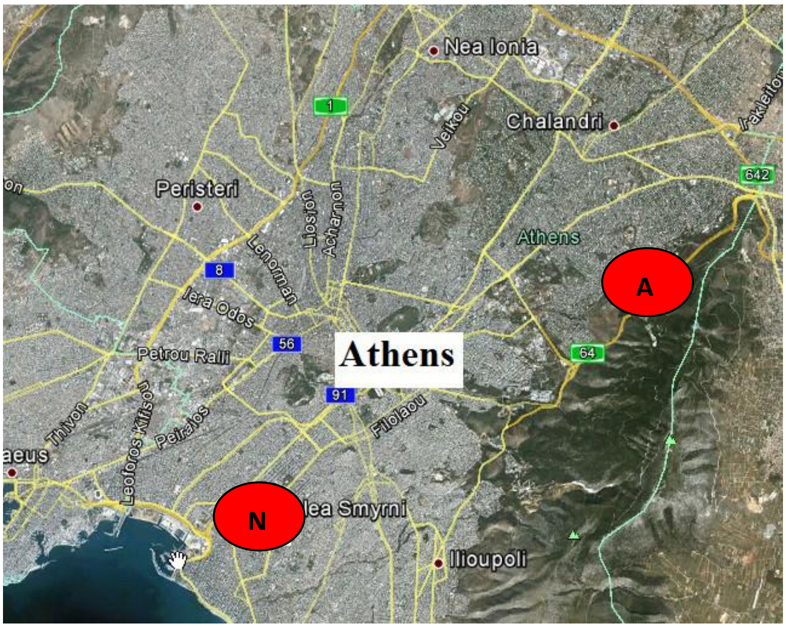

Figure 1 Map of the AMA (Athens Metropolitan Area) with the ACEPT-AIR sampling sites (AP: Agia Paraskevi, NS: Nea Smyrni).

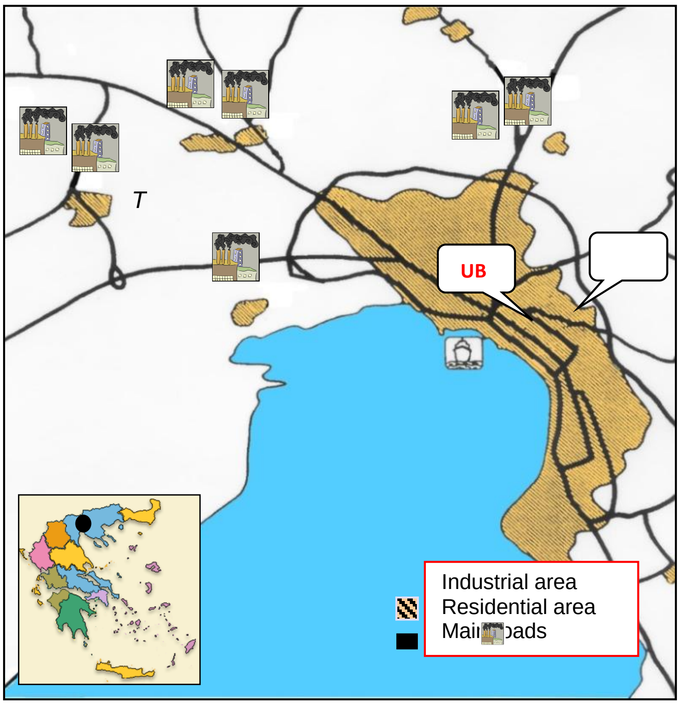

Figure 2 Map of TMA (Thessaloniki Metropolitan Area) with the ACEPT-AIR sampling sites (UT: urban-traffic, UB: urban background)

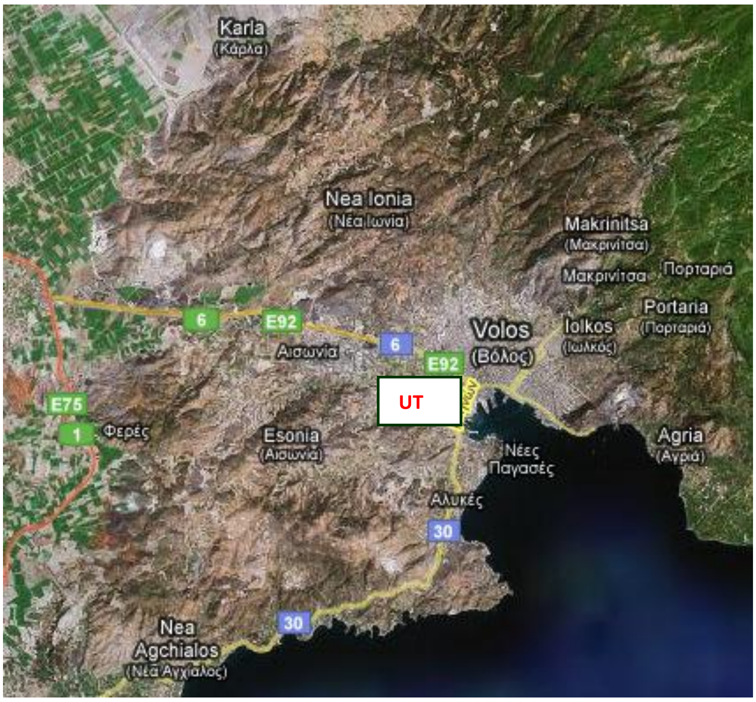

Figure 3 Map of VGA (Volos Greater Area) with the ACEPT-AIR sampling site at the University of Thessaly (UTH).

AMA, sprawling over 2,928.72 km^2, is located within the 3,808 km^2 Attica region that encompasses the most populated region of Greece, reaching 3,827,624 inhabitants in 2011. Athens (37°59' N, 23° 44' E), the capital and largest city of Greece, sprawls across the central plain of Atticabuilt around a number of hills. The climate in AMA is Mediterranean with hot dry summers and wet mild winters. The daily average winter and summer temperatures are 9.9°C and 28.6°C, respectively. The geomorphology of AMA is deemed to be one of the most complex in the world due to its mountains causing temperature inversions frequently. The ACEPT-AIR sampling sites in AMA were located at Agia Paraskevi (AP), at the urban background station GAW-DEM[1] of the National Centre for Scientific Research "Demokritos"(270 m asl), and at the urban background station of the National Monitoring Network at Nea Smyrni (NS) (50 m asl). PM sampling at both sites was conducted at a height of around 10 m above ground.

TMA extends over an area of 1,455.62 km^2 and its population in 2011 reached a total of 1,104,460 inhabitants. Built at the innermost point of Thermaikos Gulf (40°62΄N, 22°95΄E), Thessaloniki is the second largest Greek city and has the second largest commercial port. The city is characterized by intense vehicular traffic in the center and several industrial establishments located W, NW and N (oil refining, petrochemical facilities, metal scrap incineration, iron and steel manufacturing, electrolytic MnO_2 production, lubricating oil recovery, cement and lime production, quarry works). The daily average winter and summer temperatures in the city are 5.3°C and 25.1°C, respectively. Prevailing winds are weak (1-3 m/s) strongly influenced by the sea breeze, while frequently occurring calms result to inadequate dispersion of atmospheric pollutants and short-range transport processes. The ACEPT-AIR sampling sites in Thessaloniki were located at an urban traffic area (UT) in the commercial city centre (11.4 m asl), and at an urban background (UB) area in the upper part of the city (174.0 m asl). At both areas ACEPT-AIR samplers were hosted in monitoring stations of the Municipality of Thessaloniki. Despite the relatively short distance between them, the two selected sites are typically characterized by the highest and lowest PM levels of the city. PM_{10} and $PM_{2.5}$ sampling was carried out from a height of around 3 m above ground.

Volos (39° 21' N, 22° 55' E) is a medium-size coastal city,with around 150,000 inhabitants, situated midway on the Greek mainland, about 326 km North of Athens and 215 km South of Thessaloniki. Built at the innermost point of the Pagasetic Gulf, Volos has the third largest commercial port in Greece. In recent decades, urbanization and increased industrialization (cement and lime production, metal scrap incineration, iron and steel manufacturing, etc) have resulted in the deterioration of air quality in the region. The daily average winter and summer temperatures in the city are 7.8°C and 27.0°C, respectively.The meteorological factors and the complex topography of the area favors air pollution episodes. The ACEPT-AIR sampling site

[1]http://gaw.empa.ch/gawsis/reports.asp

in Volos was located on the roof of the University of Thessaly, at a height of around 9 m above ground.

2.2 Sampling methods

At all sites, PM_{10} and $PM_{2.5}$ sampling was carried out concurrently according to the reference methods ISO/IEC EN-12341 and ISO/IEC EN-14907, respectively.

Low volume air samplers equipped with PM_{10} and $PM_{2.5}$ inlets were employed operating at constant flowrate of 2.3 m^3/h. Each $PM_{10}/PM_{2.5}$ sampling had a 24-h duration. Each PM fraction was concurrently collected on two filter media:Φ47 mm Teflon filter (Zefluor^{TM}membranes, Pall 2μm) for subsequent analysis of elements and ionic species, and Φ47 Quartz filter (Tissuquartz, Pall) for subsequent analysis of organic and elemental carbon, OC and EC. Two types of air samplers were purchased in the framework of ACEPT-AIR project and were used in field measurements: Low Volume Samplers with manual filter changing (Figure 2.4a) and Sequential Samplers with automatic filter changingand Peltier cooler (Figure 2.4b).

The PM_{10} and $PM_{2.5}$ masses were gravimetrically determined according to EN-12341 and EN-14907, respectively. Loaded and unloaded filters were conditioned for 48 h at 20±1 °C and 50±5% relative humidity before weighing in a microbalance (d = 0.01 mg). Filter samples were stored ina cool and dark place until analysis (for less than four weeks).

Figure 4 Photo of the Low Volume Sampler, LVS3.2 Norbent Derenda Berlin (right side) and photo of the Sequential Sampler ($PM_{10}/_{2.5}$ SEQ 47/50-CD with Peltier cooler / 8m³-pump, Sven Leckel GmbH) (left side).

2.3 Description of the PM_{10} and $PM_{2.5}$ sampling campaigns

A summary description of the PM_{10} and $PM_{2.5}$ sampling campaigns in AMA, TMA and VGA is provided in Table 1.

Table 1 Summary description of the PM_{10} and $PM_{2.5}$ sampling campaigns in AMA, TMA and VGA.

Site	Sampling period		Number of samples	
			PM_{10}	$PM_{2.5}$
		AMA		
AP	Warm	7/7-2/10/11	48	49
	Cold	16/1-10/4/12	47	48
NS	Warm	7/7-2/10/11	40	42
	Cold	16/1-10/4/12	41	39
		TMA		
UT	Warm	30/6 - 25/9/11	28	28
	Cold	10/2 - 6/4/12	26	26
UB	Warm	14/7 - 1/10/11	26	25
	Cold	10/2 - 6/4/12	24	24
		VGA		
UTH	Warm	5/8 – 5/9/11	9	32
	Cold	20/2 – 17/3/12	23	24

2.4 Description of the PM_{10} and $PM_{2.5}$ ACEPT-AIR Database

All the data collected in the framework of the project (both historical and current) have been introduced into a Database which is submitted as a Deliverable for Action

2. The ACEPT-AIR Database provides information for PM_{10} and $PM_{2.5}$ mass and the concentration levels of their components for the Athens Metropolitan Area (AMA), the Thessaloniki Metropolitan Area (TMA), and the Volos Greater Area (VGA). The Database was constructed in Access 2010 (Microsoft Office, Windows) and has two platforms (Figure 2.5):

- The **Historical Data** platform, that includes concentrations for PM mass and chemical constituents measured at various sites inside the aforementioned areas during the period 2000-2010. The source of these data are previous measurements by ACEPT-AIR partners, records of the air pollution monitoring stations operated by national and local authorities (Greek Ministry of Environment, Municipality of Thessaloniki, etc), as well as published data of independent researchers. The historical data were collected in the framework of the project and were examined with respect to sampling protocols, sampling and analytical methods and data analysis. After being submitted to strict quality control procedures, the collected data have been introduced in the historical database.
- The **LIFE Data**platform,that includes concentrations of PM_{10} and $PM_{2.5}$ and their associated chemical components, measured during 2011-2012 in the framework of the ACEPT-AIR project.

Figure 5 Introduction page to the ACEPT-AIR Database.

Both platforms have the same structure (Figure 6). The user can have access to the data by selecting various options regarding the identity and characteristics of the sampling site:

- **The study area.** The user can select among the Athens Metropolitan Area (AMA), the Thessaloniki Metropolitan Area (TMA), and the Volos Greater Area (VGA).
- **The specific in each area.** By this selection, a map from the Google maps also comes into view.
- The **authority** that was responsible for this station (Ministry of Environment, Municipality of Thessaloniki, etc).
- The **characterization** of the station regarding the distance from various sources (i.e. urban-traffic, urban background, industrial).
- The **pollutants** that are usually measured, besides PM mass (CO, NOx, SO_2, O_3, etc).

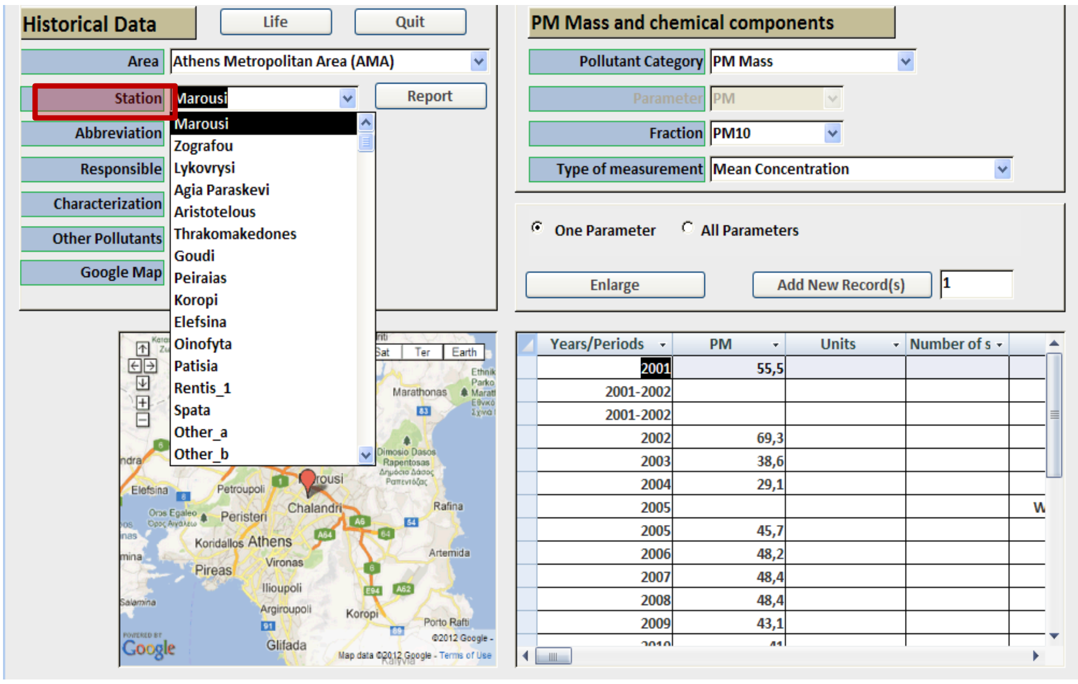

Figure 6 Historical PM_{10} data at the Marousi station in AMA.

For PM mass, the user can select the size fraction (PM_{10}, $PM_{2.5}$, Total Suspended Particles - TSP or other) (Figure 7), as well as specific statistics of data (mean values, percentiles, min and max values) (Figure 8).

Besides PM mass, the Database provides information for the chemical components of PM, such as elemental components, ionic components, organic compounds, and carbonaceous species.

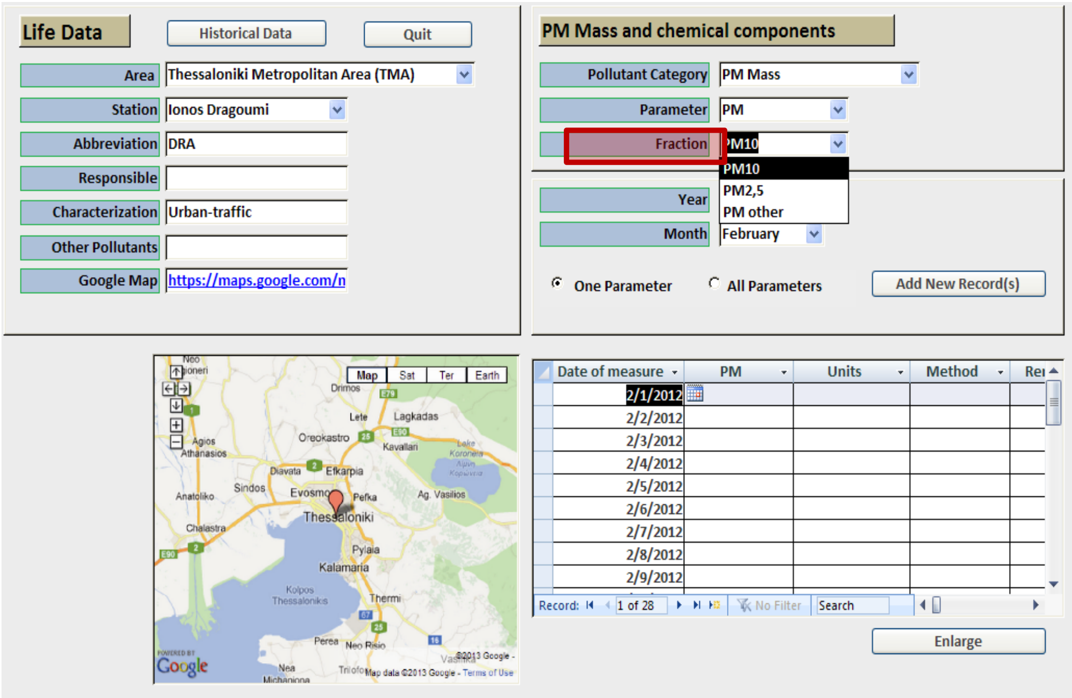

Figure 7 LIFE data for PM_{10} at the Ionos Dragoumi station in TMA.

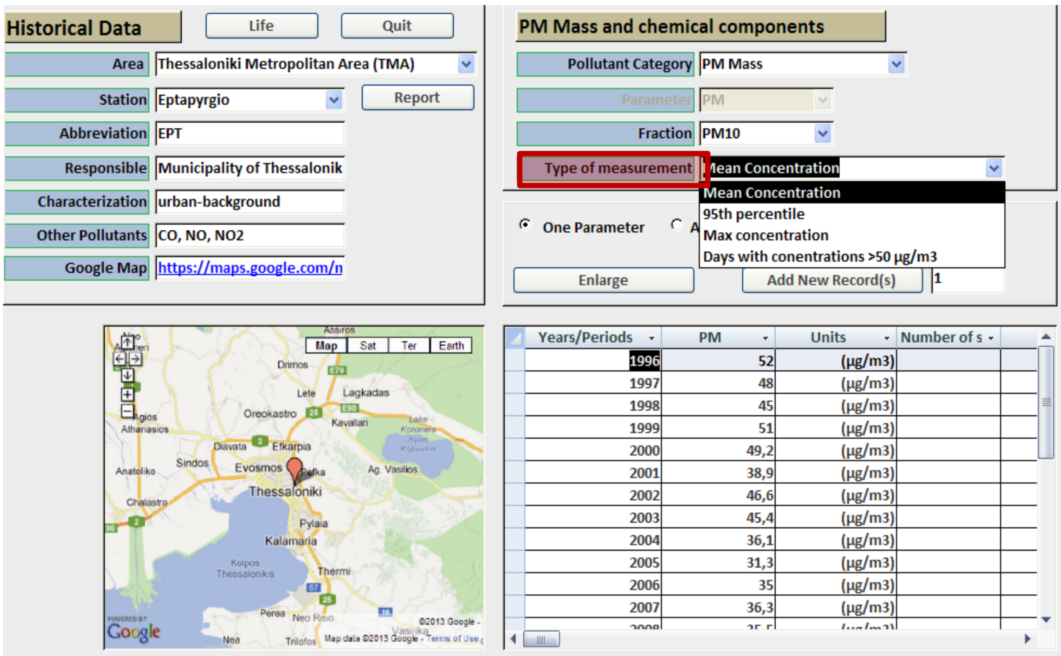

Figure 8 Historical mean concentrations of PM_{10} at Eptapyrgio station in TMA.

3. RESULTS AND DISCUSSION

3.1. Historical data for PM_{10} and $PM_{2.5}$ in AMA, TMA and VGA

Temporal trendsof historical PM_{10} and $PM_{2.5}$ concentrations in AMA, TMA and VGA are shown in Figures 9 to 13 for traffic, industrial and background sites, respectively. A strong decreasing trend of PM_{10} and $PM_{2.5}$ levels during the last two decades is apparent, particularly at traffic sites, as a result of pollution abatement measures including improvement regarding the age of the vehicle fleet and the corresponding engine technology, improvement of fuel quality, increased use of natural gas for space heating and energy production in industry, etc. (Petrakakis et al., 2013; Triantafyllou & Biskos, 2012; Aleksandropoulou et al., 2011; Argyropoulos et al., 2011).

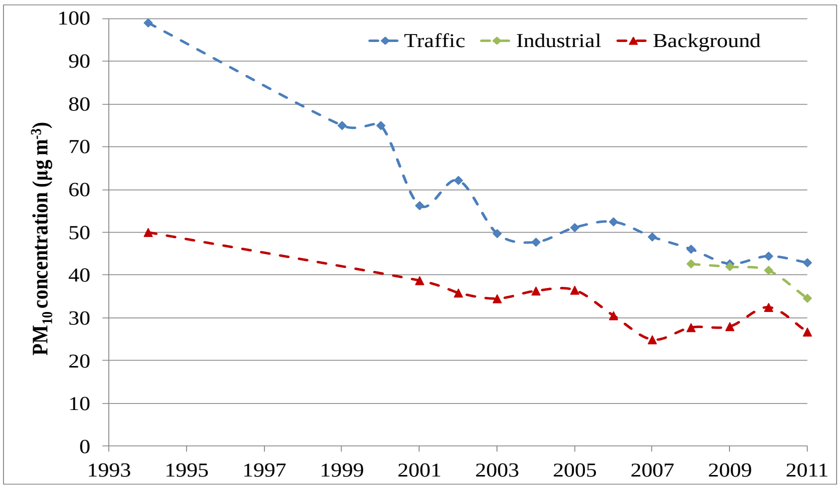

Figure 9 Evolution of mean yearly PM_{10} concentrations for traffic, industrial and background sites in AMA.

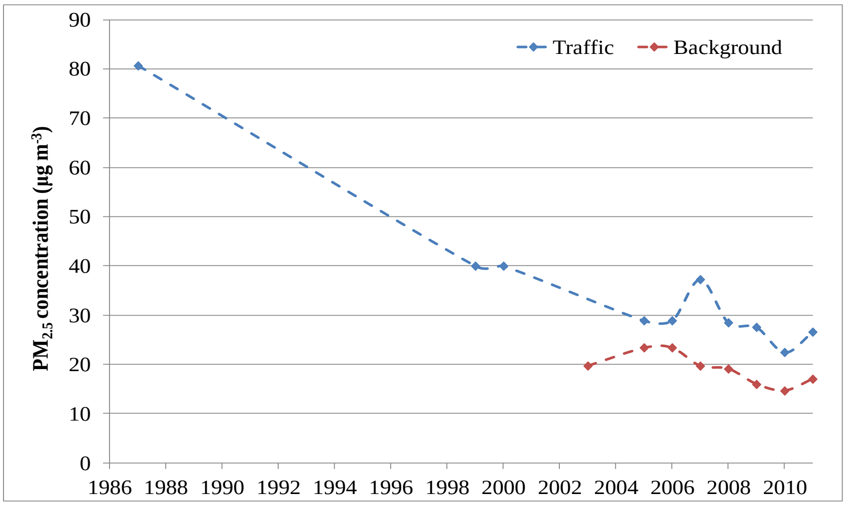

Figure 10 Evolution of mean yearly $PM_{2.5}$ concentrations for traffic and background sites in AMA.

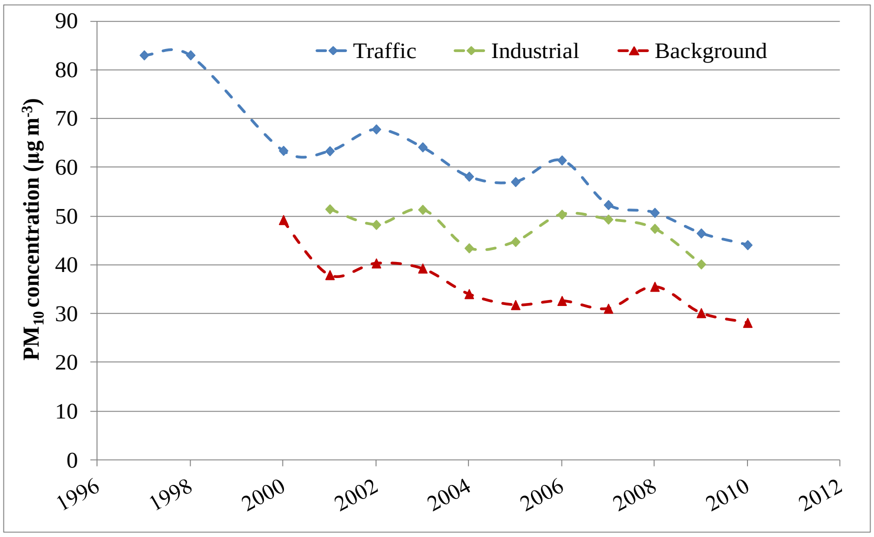

Figure 11 Evolution of mean yearly PM_{10} concentrations for traffic, industrial and background sites in TMA.

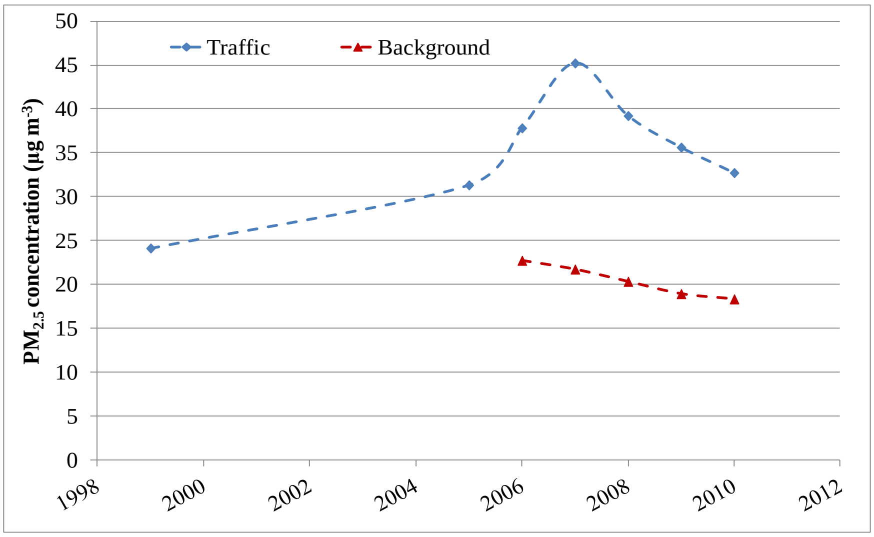

Figure 12 Evolution of mean yearly $PM_{2.5}$ concentrations, for traffic and background sites in TMA.

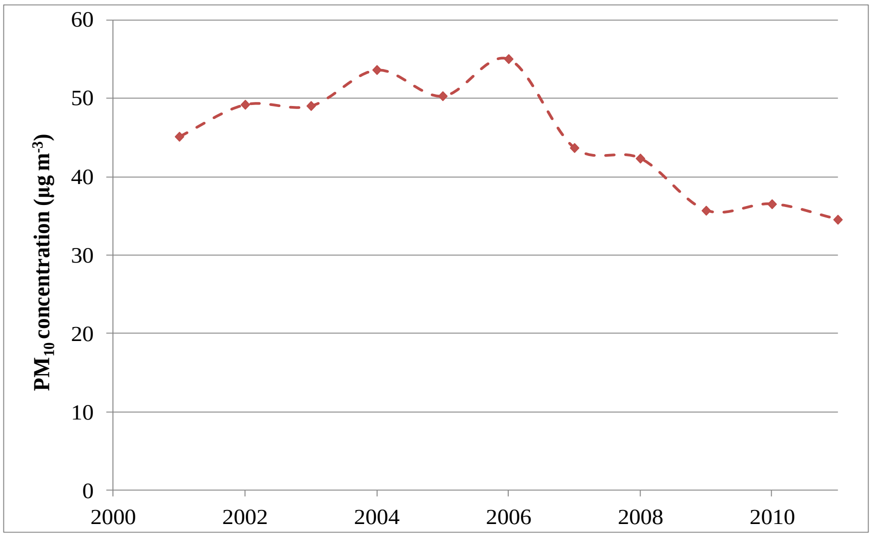

Figure 13 Evolution of mean yearly PM_{10} concentrations in VGA (centre of Volos).

3.2. ACEPT-AIR data for PM_{10} and $PM_{2.5}$ in AMA, TMA and VGA

3.2.1. Concentrations of PM_{10} and $PM_{2.5}$

Mean PM_{10} and $PM_{2.5}$ concentration levels measured during warm and cold season ACEPT-AIR campaigns are presented in Figures 14 and 15, respectively. During warm season, PM_{10} concentrations at the two background sites in Athens, the urban background site in Thessaloniki and in Volos were always below the 24-hr limit value of 50 μg m^{-3} set by Directive 2008/50/EC (with the exception of one day in AP where PM_{10} concentration barely exceeded 50 μg m^{-3}). As expected, the respective levels at the traffic site in Thessaloniki were higher, with 13 out of 28 days exceeding the 24-hr limit value. Similarly, $PM_{2.5}$ levels during warm season were above the yearly target value set by EU (25 μg m^{-3}) only in TMA/UT.

During cold season mean PM_{10} and $PM_{2.5}$ concentrations were significantly higher with respect to warm period, at all sites except for AP in AMA. In addition, 24-hr concentrations for both size fractions exhibited a much large variability, with peak concentrations reaching up to more than three times the 24-hr limit value for PM_{10} and the yearly target value for $PM_{2.5}$. Exceedances of the PM_{10} 24-hr limit value were observed at all sites The lowest concentration levels were again measured at the background sites; nonetheless both AP background station and Thessaloniki background site presented 2 (out of 47) and 4 (out of 24) days with exceedance incidents. At the more densely populated site of NS in Athens, and in Volos, PM_{10} concentrations were above the 50 μg m^{-3} limit value for 33% and 70% of the measurement days respectively, while mean cold season concentration in Volos was much higher than the annual limit value (74 μg m^{-3}). $PM_{2.5}$ levels were significant as well, with mean cold season values close or higher than the annual target value of 25 μg m^{-3}. The results suggest a strong PM source during cold season, present also in background residential sites (such as residential heating), as well as meteorological conditions favouring air pollution episodes during cold season (lower dispersion of pollutants).

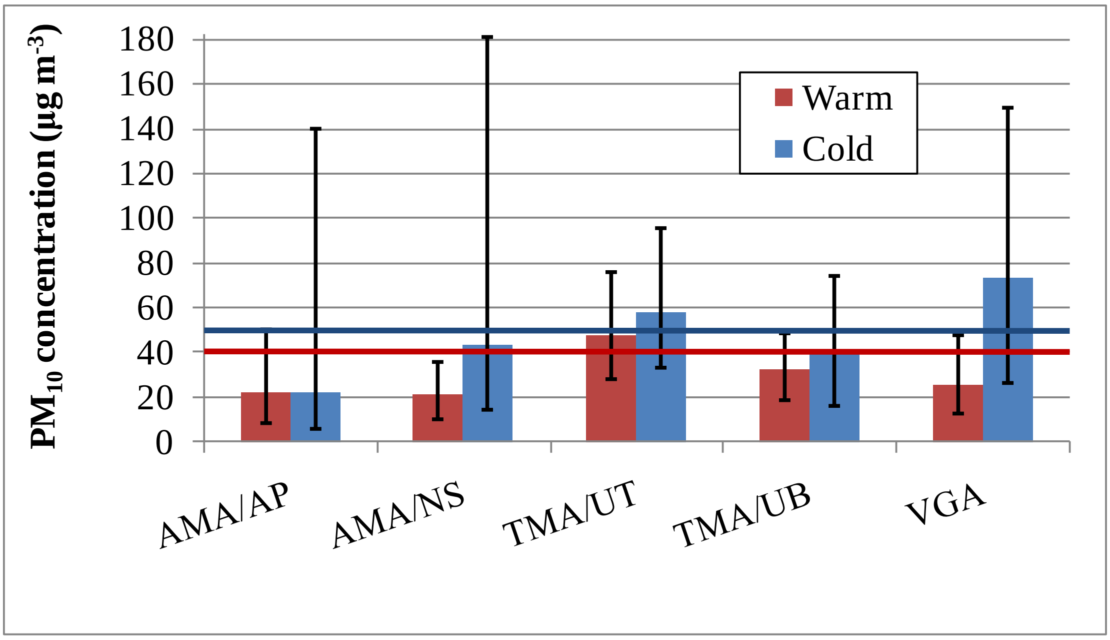

Figure 14 PM_{10} concentrations during warm and cold seasons on the various sampling sites. Columns correspond to mean values and error bars denote range of 24-hr values. Blue and red lines depict the 24-hr and the yearly EU limit value for PM_{10}, respectively.

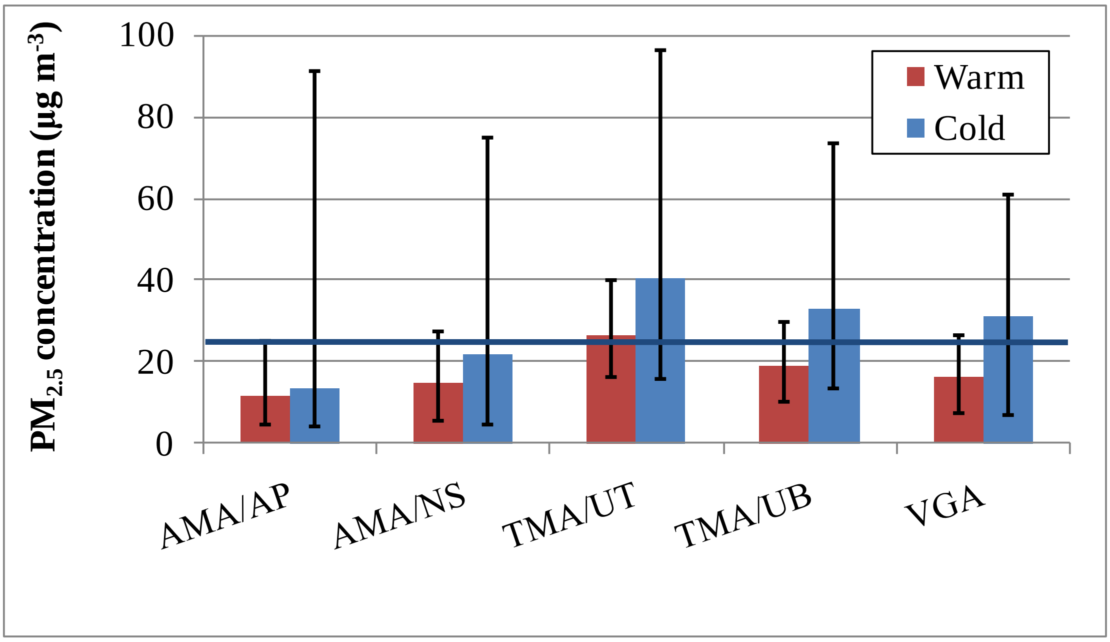

Figure 15 $PM_{2.5}$ concentrations during warm and cold seasons on the various sampling sites. Columns correspond to mean values and error bars denote range of 24-hr values. Blue line depicts the EU yearly target value for $PM_{2.5}$.

Yearly mean PM_{10} concentrations (Figure16) exceeded the annual limit value of the air quality directive 2008/EC/50 (40 μg m^{-3}) at the traffic site inThessaloniki (TMA-UT) and in Volos. Correspondingly, the yearly mean $PM_{2.5}$ concentrations exceeded the annual target valueof 25μg m^{-3}at both sites in TMA, while in Volos it was only slightly lower (Figure17).

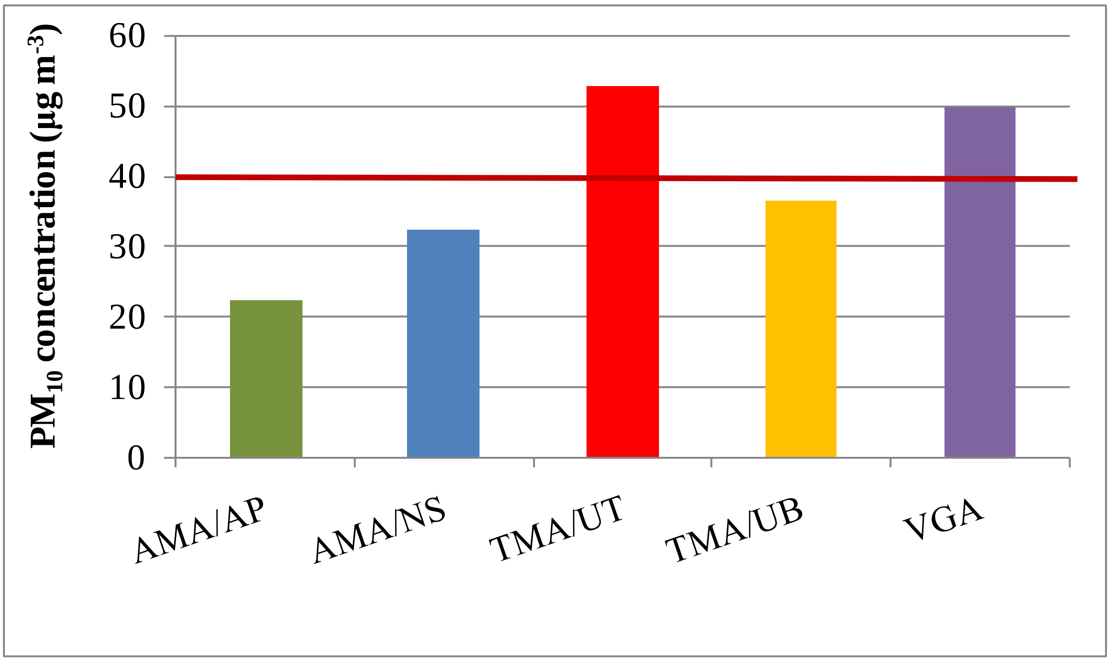

Figure 16 Mean PM_{10} concentrations at the sampling sites of the ACEPT-AIR project. Red line depicts the EU yearly limit value for PM_{10}.

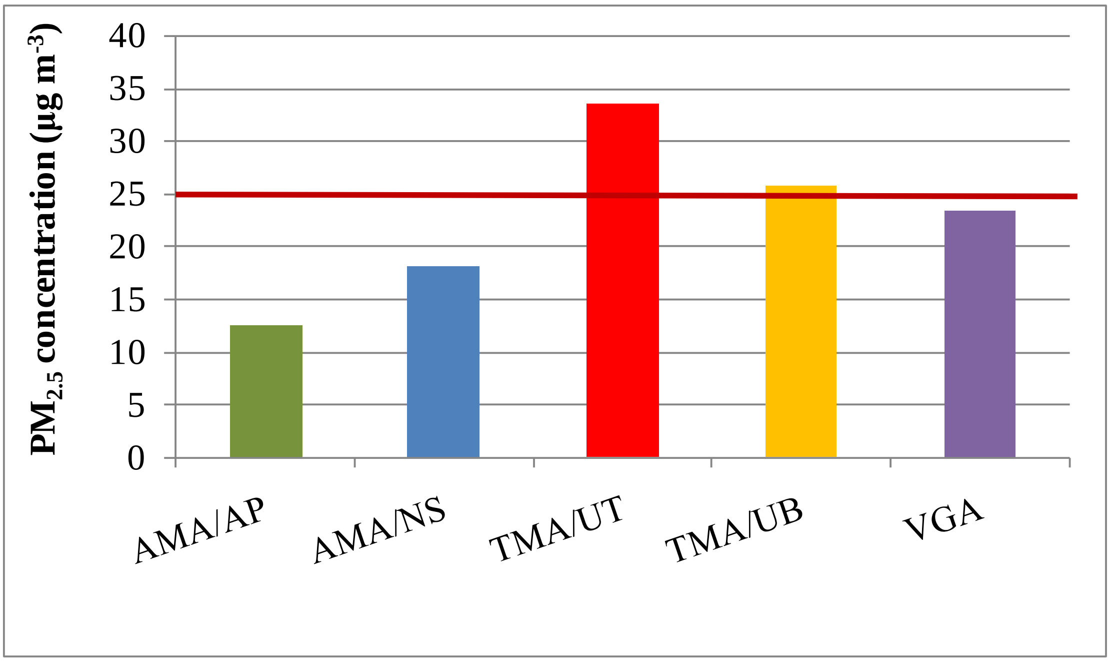

Figure 17 Mean $PM_{2.5}$ concentrations at the sampling sites of the ACEPT-AIR project. Red line depicts the EU target value for $PM_{2.5}$.

In general, PM_{10} and $PM_{2.5}$ concentrations observed at this study were similar to the concentrations usually found at urban sites in Greece, as well as at other urban sites of South and Central Europe with similar characteristics (Karanasiou et al., 2014; Tolis et al., 2014; Manousakas et al., 2013; Theodosi et al., 2011).

3.2.2. Distribution in the fine and coarse fractions

The distribution of PM_{10} mass in the fine ($PM_{2.5}$) and the coarse ($PM_{2.5-10}$) particle fractions is shown in Figures 18 and 19. Coarse and fine particles contributed similarly to PM_{10} mass in AMA/AP during warm season when dry conditions favored the resuspension of coarse particles (such as mineral dust). During cold season the fine fraction was larger than the coarse fraction, suggesting increased emissions of $PM_{2.5}$ probably from combustion sources (such as residential heating and traffic). Similar trends were observed in TMA UB and UT sites. The opposite seasonal trend was observed in AMA/NS and VGA where $PM_{2.5}$ contribution was larger during warm season, pointing towards secondary formation due to high photochemical activity. A significant coarse particle source was present during cold season in VGA, where $PM_{2.5-10}$ contribution to PM_{10} was the highest from all sites and seasons (Proias et al., 2012).

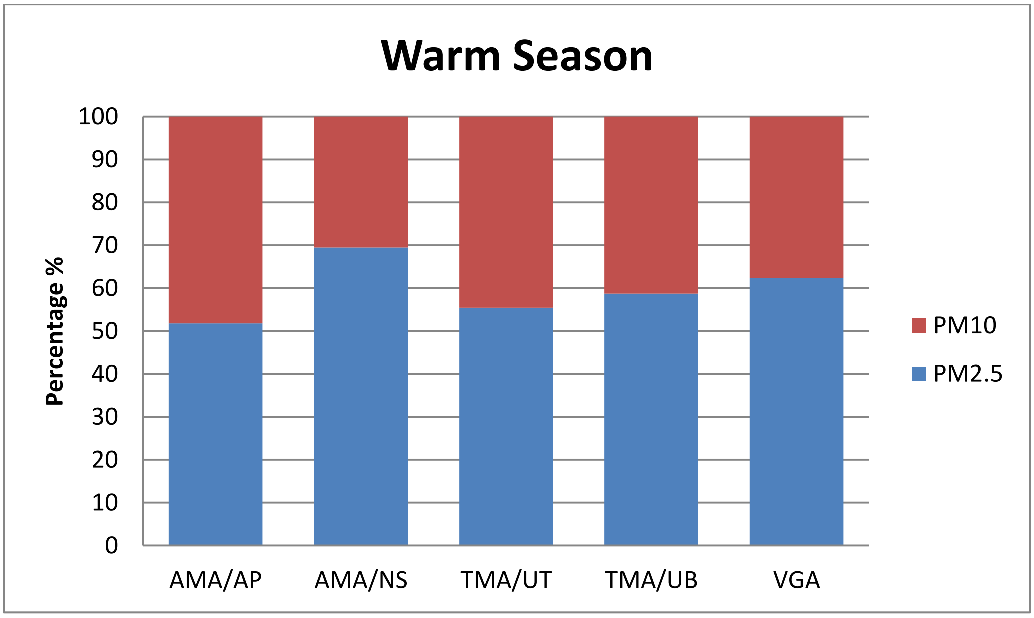

Figure 18 Percentages of the fine fraction ($PM_{2.5}$) and the coarse fraction ($PM_{2.5-10}$) in PM for every sampling site in the warm season.

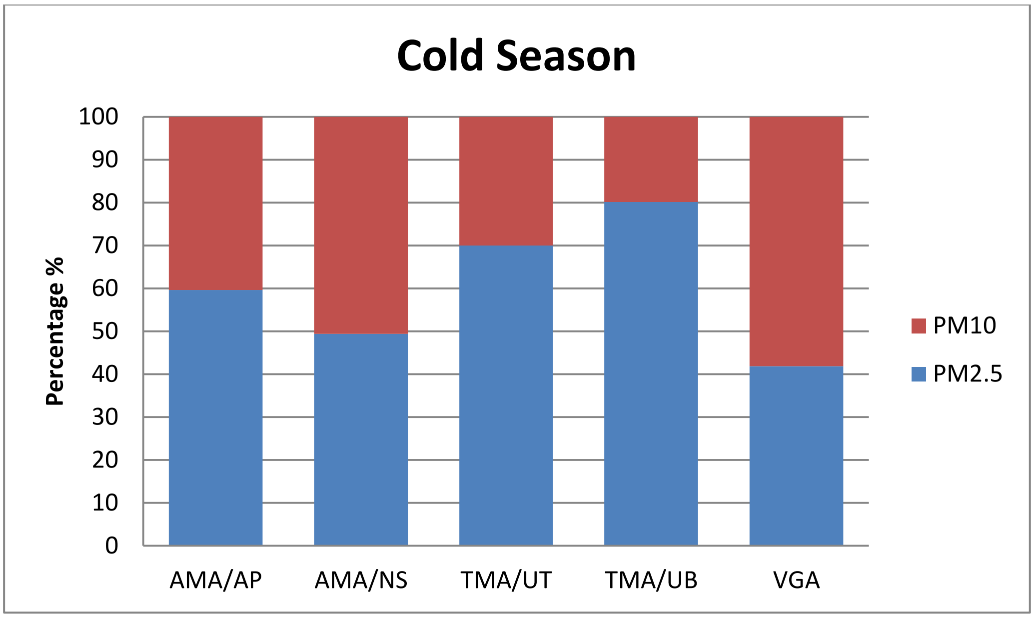

Figure 19 Percentages of the fine fraction ($PM_{2.5}$) and the coarse fraction ($PM_{2.5\text{-}10}$) in PM for every sampling site in the cold season.

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