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SOURCE-RECEPTOR RELATIONSHIPS BY USING DISPERSION MODEL IN A LIGNITE BURNING AREA IN WESTERN MACEDONIA, GREECE

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ABSTRACT

Quantifying the contribution of individual sources to air pollution in one area is the first essential step in managing air quality in this region. This is of great interest especially in areas with combined urban and industrial emission sources. The area of Western Macedonia is a very complex in terms of air quality management problem because of large and complex pollution sources operating in the region. The emissions from five lignite power plants (LPP) operating in this region, the corresponding opencast lignite mining, as well as the urban activities in the industrial axis, is a complex problem to quantify the contribution of these sources in a spatial and temporal scale in the region. This paper attempts to quantify the contribution of LPP to the particulate pollution of this region, using PM_{10} concentrations measurements and simulations. Specifically were used: a) suspended particulate PM_{10} concentration measurements for a two years period (2009-2010) at various locations in the region and b) simulations of atmospheric dispersion. The results showed that the LPPs contribution to the PM_{10} concentrations of the regions studied ranged from 27-84% when the background was removed. These results were also confirmed by the corresponding Index of Agreement (IOA) between the mean monthly model calculations and the station measurements after removing the background. The LPPs contribution to the PM_{10} concentrations was a factor of the distance between the receptor area and the LPP, while the presence of other PM_{10} sources was found also to contribute at a higher or a lesser extent, depending on the area's activities (e.g. urban, agricultural etc) and seasonal characteristics.

KEYWORDS: source attribution, lignite power plants, dispersion models.

INTRODUCTION

An important step for the air quality management in a region and the consequent implementation of the necessary measures aiming towards the most effective treatment of atmospheric pollution problems, are source apportionment studies. Six methods for attributing ambient pollutants to emission sources are usually used: emissions analysis, trend analysis, tracer studies, trajectory analysis, receptor modeling and dispersion modeling (Blanchard, 1999). Dispersion models are well suited for estimating quantitative source-receptor relationships, because the effect of individual emission sources or source regions on predicted ambient concentrations can be studied. This method was selected in this study for attributing ambient pollutants to emission sources in the Amyntaion – Ptolemais- Kozani Basin (APKB), a complex terrain area in NW Greece.

The area is characterized by an intensive industrial activity with 5 lignite combustion power plants and open pit mines. In addition the different types of pollution sources in this area related with urban and agricultural/burning biomass activities, result in huge amount of pollutants' emissions, mainly dust emissions, and high PM_{10} concentrations (Triantafyllou, 2003). Different residential areas (receptors) are affected by different sources or a combination of sources, under different meteorological conditions. This fact, in conjunction with the variety of pollution sources and the topography complexity render the source apportionment study of this area an interesting case study.

There are only a limited number of works which attempt to study the contribution of the different pollution sources to the PM_{10} concentrations in the area. Triantafyllou and Kassomenos (2002) investigated the atmospheric conditions which favor the pollutants' transport emitted by the LPP, by using a coupled atmospheric mesoscale model and Lagranian dispersion model. Samara (2005) employed a CMB receptor model to determine contributions to ambient TSP levels at the different receptor sites in APKB, while Tolis *et al.* (2011) made a preliminary source apportionment study for the city of Kozani conducted through a PMF model application. The current study is focused on the investigation of the LPP emissions' contribution to the PM_{10} pollution in urban and agricultural areas of APKB for a two years period (2009-2010). Actually, the receptor areas under study were: Kozani (urban), Pontokomi (industrial-residential), Petrana (agricultural), Koilada (industrial - agricultural), Amyntaio (agricultural) and K. Komi (agricultural). The receptors were selected in order to cover the whole basin. Meteorological observations, PM_{10} concentration measurements and simulations of atmospheric dispersion are used for the period under study.

DATA AND METHODOLOGY

Study Area

APKB is located in the middle of Western Macedonia, GREECE, that is characterized as a broad, relatively flat bottom basin surrounded by tall mountains with heights 600-more than 2000-m above Mean Sea level (Figure 1). The climate of the area is continental Mediterranean with low temperatures during winter and high ones during summer. The winds in the center of the basin blow mostly along the NW/SE axis due to channeling of the synoptic wind, since the NW/SE axis coincides with the major geographical axis of the basin. Four lignite power stations (Figure 1) operate in the basin with lignite mined in the nearby open pit mines, resulting in the greatest amount of the total electrical energy produced in Greece. One lignite power station 675 MW (PS6) also operates in Bitola/FYROM, close to the border with the area under interest. Considerable amounts of fly ash and fugitive dust are emitted from the LPPs stacks and mining operations (Triantafyllou, 2003). In the two major towns of the area (Kozani and Ptolemais) about 100.000 people live and work. There are also several villages with population ranging from several 100s to several 1000s of inhabitants.

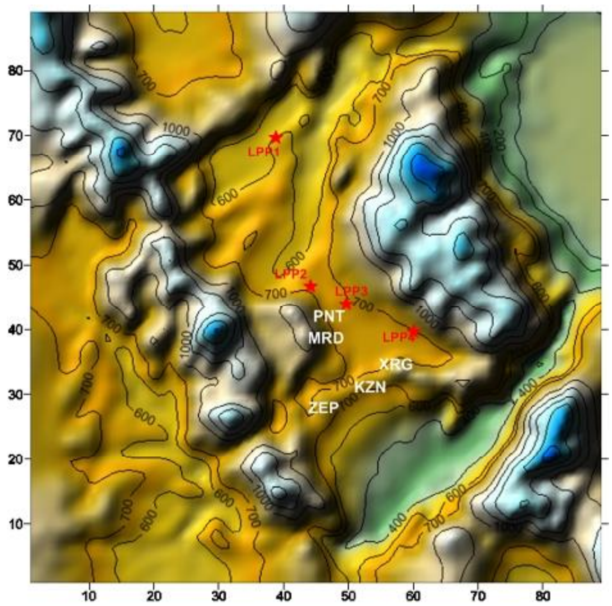

Figure 1. The topography of the APKB industrial basin greater area showing the locations of the lignite power plants (LPP1,…,4). The location of the major town of the area, Kozani, as well as the monitoring network of LAP-EP are also shown. Elevations are in meters

The dispersion model (TAPM)

TAPM is a nestable, prognostic meteorological and air pollution model that solves fundamental fluid dynamics and scalar transport equations to predict meteorology and pollutant concentration for a range of pollutants important for air pollution applications. For computational efficiency, it includes a nested approach for meteorology and air pollution, with the pollution grids optionally being able to be configured for a sub-region and/or at finer grid spacing than the meteorological grid, which allows a user to zoom-in to a local region of interest quite rapidly. TAPM includes chemistry and deposition modes, where specific pollutants and their interaction with each other are represented. Eulerian and Langragian modules are also exist as an option to the user, for a more accurate simulation. TAPM is also able to dynamically downscale 1^{o} resolution National Centre for Environmental Prediction (NCEP) Global Forecasting System (GFS) analyses to local -–scales for environmental applications. More information can be found in (Triantafyllou *et al*., 2011; Hurley *et al*., 2005).

The model run for a two years' period using 25 vertical model levels, and three nested domains of 25x25 horizontal grid points at 30, 10 and 3-km spacing for the meteorology, and 141x221 horizontal grid points at 3, 1, and 0.3-km spacing for the pollution using an Eulerian module approach without chemistry applied. NCEP synoptic analyses were used at the outer grid boundaries. The stacks of the 4 LPP in the APKB (3 stacks for Agios Dimitrios, 4 stacks for Kardia, 3 stacks for Ptolemaida and 1 stack for Amyntaion) were employed as emission sources, with their coordinates being obtained by the Universal Transverse Mercator. Pontokomi was considered as the center (0,0,0).

The required mean lignite amount for a 1200 MW power station is estimated at 54 000 t day^{-1}. Given that a mean percentage of 15% of the fuel is converted to ash, the unit has a mean combustion waste production of about 8100 t day^{-1}. If a 99.9% efficiency rate is assumed for the electrostatic precipitators, nearly 8.5 tones of fly ash per day are transferred to the atmosphere as primary particulate pollutant. The aforementioned theoretical efficiency can be much lower depending on the lignite characteristics and the oldness of precipitators. In the current study, a lower efficiency of 99% was assumed while the corresponding emissions (81 tones of fly ash per day) were considered constant.

RESULTS AND DISCUSSION

PM_{10} background concentrations computation

The PM_{10} background calculation is carried out either by subtracting the local sources contribution calculated by the model from the measured concentration in a distant station or by discriminating pollution measurements according to the wind direction (Kakosimos *et al*., 2011). The mean monthly background for the 2 years studied was calculated here following the first method for K. Komi (the most distant station), and the mean value was estimated 20 μg m^{-3}. This value was confirmed by the pollution rose of the same area (Figure 2a), which gives the same value for wind blowing from the opposite (Figure 2b) to the LPPs direction (19 μg m^{-3}). Since the results of both methods vary for only 1 μg m^{-3}, the first calculation method was preferred for the background estimation as the most straightforward. It should be mentioned that due to lack of measurements in K. Komi station in January and February of both years, all the calculations were carried out for the months March to December.

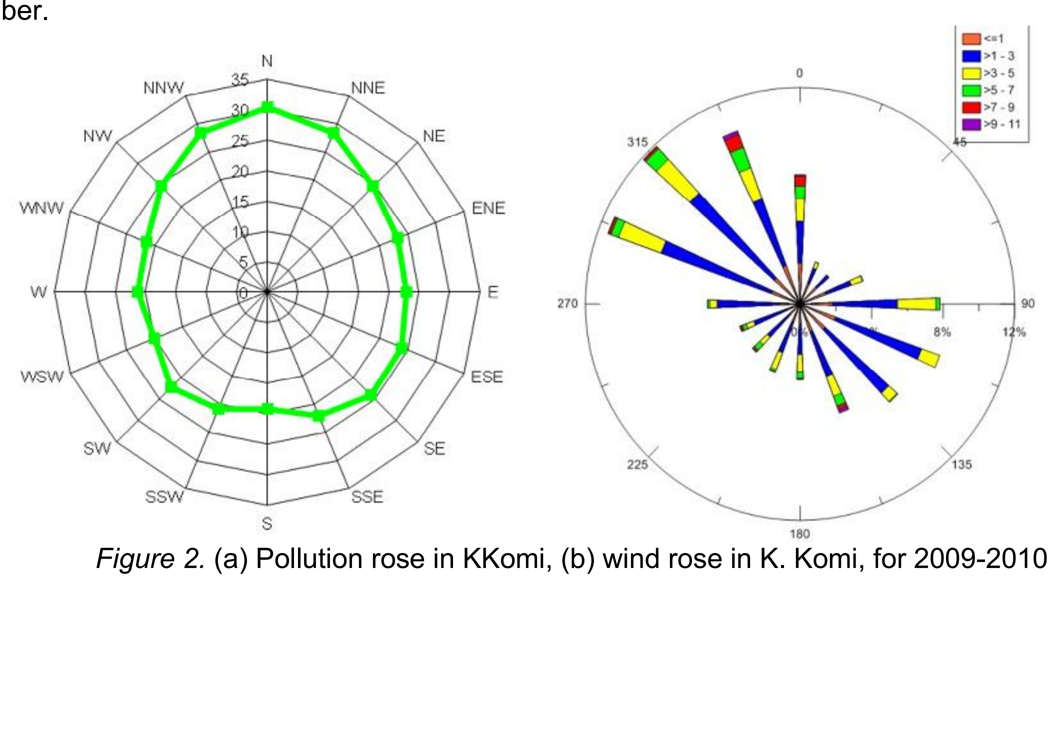

Figure 2. (a) Pollution rose in KKomi, (b) wind rose in K. Komi, for 2009-2010

Spatial distribution of PM_{10} concentrations

The spatial distribution of PM_{10} concentrations due to LPP contribution was calculated for each of the two years studied (2009-2010). Figure 3 shows the PM_{10} annual average concentration contours in APKB for 2009 and 2010. The highest PM_{10} concentration calculated from TAPM model corresponded to receptors around the LPP sources. On the other hand, the PM_{10} contribution of LPPs to receptors outside the basin was found much lower (3 μg m^{-3}) in both south and north areas.

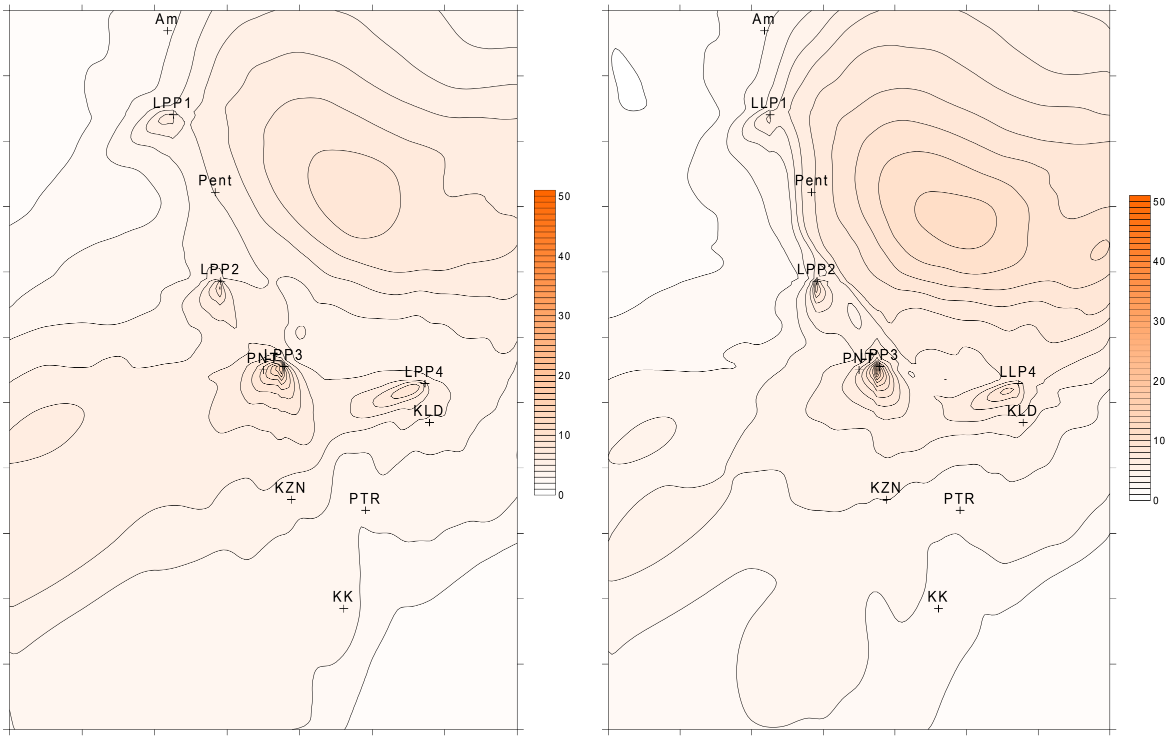

Figure 3. Annual average concentration contours of PM_{10} originated from LPPs a) 2009 and b) 2010. Concentrations are given in μg m^{-3}. Am: Amyntaio, Pent.: Pentavrisos, P: Pontokomi, KLD: Koilada, KZN: Kozani, PTR: Petrana, KK: Kato Komi

As already mentioned, the prevailing winds in the basin are the NW/SE ones. However, the annual average contours of PM_{10} resulted by the model (Figure 3), show a rather unexpected orientation. This may be related to the boundary layer evolution and the mixing height variation in the basin in relation to the synoptic circulation. This issue is under investigation in LAP-EP.

Comparison with measurements by monitoring stations

According to the method applied for background measurements, the sum of the calculated by TAPM concentrations (corresponding to calculated LPPs PM_{10} concentrations) and the background is equal to the measured PM_{10} values minus the contribution of other sources in each receptor. This concept is described by the following equation 1

[Measured PM_{10} concentration] - [other sources] = [LPP (TAPM)] + [background] (1)

In order to reveal the LPP's contribution to the PM_{10} concentration of the studied receptor areas, the Index of Agreement (IOA) between the mean monthly concentrations calculated by the model ([mean monthly LPP (TAPM)]) and the mean monthly measured PM_{10} concentrations minus the mean monthly background concentrations ([mean monthly Measured PM_{10} concentration]- [background]) for every measurement station was calculated. Since background is more representative in a monthly than in a daily basis, all calculations were performed using monthly values.

The IOA is a measure of how well predicted variations around the observed mean are represented and ranges from 0 to 1, with a larger number indicating a more accurate forecast. This index was proposed by Willmott (1981) as an alternative for r (correlation coefficient) and r^2 (coefficient of determination), since the latter are not consistently related to the accuracy of calculation. An IOA greater than 0.5 is generally considered as a good calculation, based on other models reported in the literature (Hurley *et al*., 2001).

In our study we calculated the IOA between the mean monthly model calculations and the station measurements after removing the background. Since equation 1 could be re-written as

[Measured PM_{10} concentration] - [background] = [LPP (TAPM)] + [other sources]

The removal of background from the measured concentration in each receptor area, represents the PM_{10} contribution of all sources, including LPPs, in the same area. Therefore, the IOA calculated in the current study, should give an indication of the LPP's fraction in the PM_{10} sources of each studied area, since the model calculations are compared to the PM_{10} emissions of all sources, including LPPs.
The results are shown in the following Table 1.

Table 1. Index of Agreement (IOA) for each measurement station and %LPPs contribution

Studied Area	**IOA**	**% LPP contribution (background included)**	**% LPP contribution (background re-moved)**
Koilada	0.71	19	84
Pontokomi	0.62	25	58
Kozani	0.47	14	45
Amyntaio	0.41	10	40
Petrana	0.39	10	27

The IOA for Koilada and Pontokomi was greater than 0.5 (Table 1). We could therefore assume that the main PM_{10} sources for both Koilada and Pontokomi are LPPs. This is rather reasonable, since both Koilada and Pontokomi are very close to LPP4 and LPP3, respectively (see Figure 1). For the rest of the studied areas the LPPs seem to have a lower contribution in the areas PM_{10} concentrations. The LPPs contribution in Kozani is higher than the one in the case of Amyntaio and Petrana, something that is also reasonable considering their place in the basin (Figure 1). However, in all three of these areas, the LPPs seem to be not the main PM_{10} sources. As already mentioned, Kozani is an urban area, therefore traffic and other urban activities or activities in the nearby mines could also contribute to the PM_{10} concentrations of the area. On the other hand, Amyntaio and Petrana are both agricultural areas, placed in the boundaries of the basin. These results were also confirmed by the % LPPs contribution calculation in each study area when the background was removed (Table 1) as well as from the mean monthly concentrations from 2009-2010 illustrated in Figures 4 - 8.

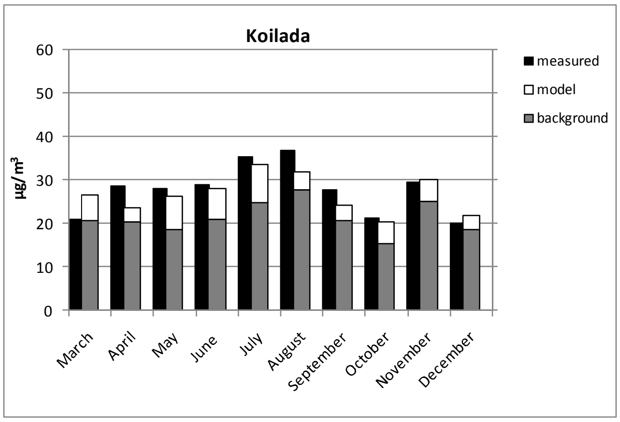

Figure 4. Monthly averaged PM_{10} concentrations calculated by TAPM plus the background concentrations compared to data from measurement stations in Koilada, 2009-2010

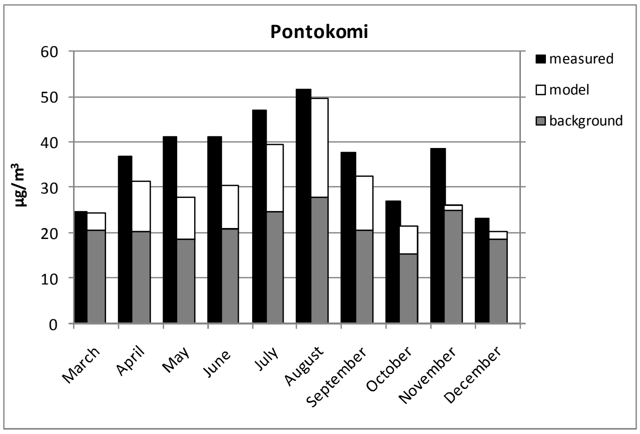

Figure 5. Monthly averaged PM_{10} concentrations calculated by TAPM plus the background concentrations compared to data from measurement stations in Pontokomi, 2009-2010

The discrepancies between the measured and the calculated PM_{10} concentrations shown in Figure 5, could be attributed to other sources since Pontokomi is an industrial –residential area and also very close to an open pit mine At this point it is worth to mention that although Pontokomi seems to be less affected by LPPs than Koilada (Table 1), higher PM_{10} concentrations were recorded for the whole period (Figure 5). Especially during June and July, the mean annual PM_{10} concentration limit of 40 μg m^{-3} was significantly exceeded. The highest PM_{10} concentration in Pontokomi was recorded during August, while for the same month the LPP contribution calculated by the model was also the highest.

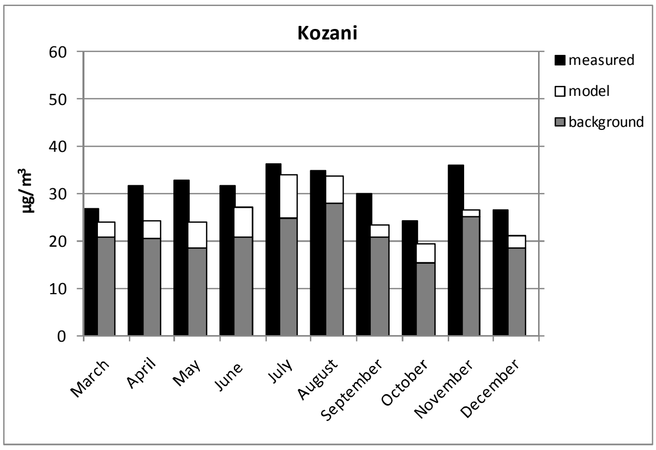

Figure 6. Monthly averaged PM_{10} concentrations calculated by TAPM plus the background concentrations compared to data from measurement stations in Kozani, 2009-2010

As far as Kozani is concerned, according to Tolis *et al*. (2011), a percentage of 23.7% of PM_{10} in Kozani is attributed to coal and lignite burning. The discrepancy in the results of the aforementioned study and the current one (14%) is explained by the fact that in the work of Tolis *et al*. (2011), the results were obtained for a very short study period (from 20/12/2009- 12/01/2010 and from 19/07-30/07/2010). In the work of Samara (2005) the LPPs contribution to TSP in Kozani is 6-8%. The higher corresponding contribution calculated by TAPM in Kozani is explained by the fact that the current work studied the PM_{10} dispersion from LPPs while the work of Samara studied TSP dispersion from the same source. Since finer particulate matter can be dispersed in a larger area, and Kozani is far from LPPs (13 km), the results seam realistic. Moreover, in the work of Samara (2005), a different source apportionment method was used (receptor modeling method).

As already mentioned, the differences between the calculated and measured values for Kozani (Figure 6), could be attributed to traffic and other sources. The contribution of traffic is clearly shown from the aforementioned graph, since during July and August the difference between the calculated and measured values is minimized.

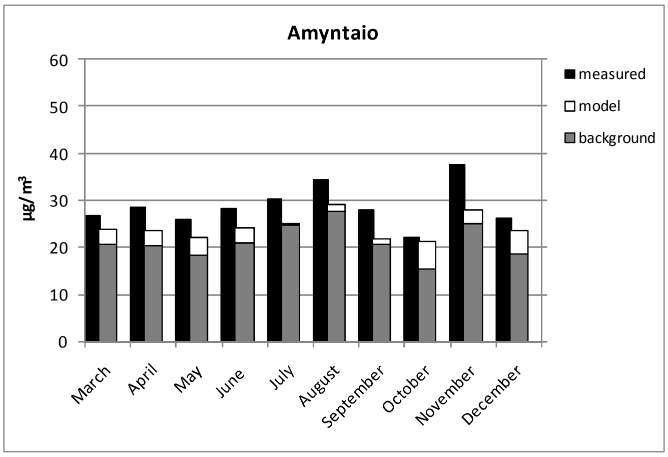

Figure 7. Monthly averaged PM_{10} concentrations calculated by TAPM plus the background concentrations compared to data from measurement stations in Amyntaio, 2009-2010

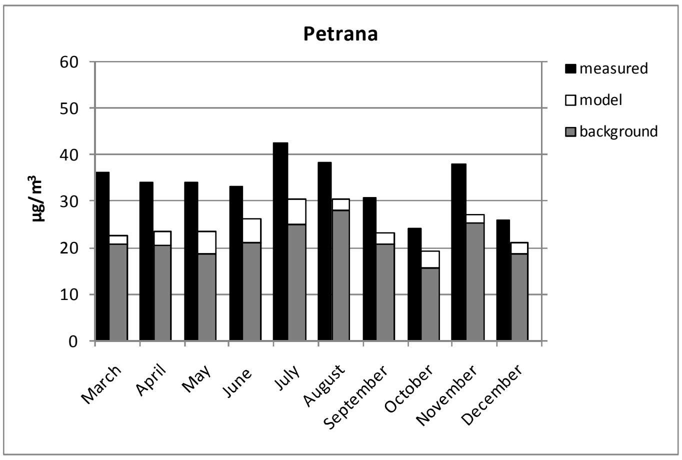

Figure 8. Monthly averaged PM_{10} concentrations calculated by TAPM plus the background concentrations compared to data from measurement stations in Amyntaio, 2009-2010

As far as Amyntaio is concerned (Figure 7), the differences between the mean monthly calculated and measured values could be attributed mainly to agricultural activities. However, it is worth to mention that during November, a large number of trucks with beets pass through Amyntaio. This situation could explain the rise in the measured PM_{10} concentration in Amyntaio during November and the highest difference between the measured and calculated values.

According to Samara (2005) the LPPs contribution to TSP in Amyntaio is 7-8%. The higher corresponding contribution calculated by TAPM in Amyntaio could be attributed to the same reason as in the case of Kozani (see above).

A one by one comparison between the modeled monthly averages (calculated as the sum of TAPM results and the background) and the measurements is also presented in Figure 9. In this Figure, the good agreement between the calculated and measured values is clearly shown. In the case of Koilada, an excellent agreement is illustrated during the whole period, since, from the aforementioned discussion, the area seemed to be mainly affected by LPPs operation.

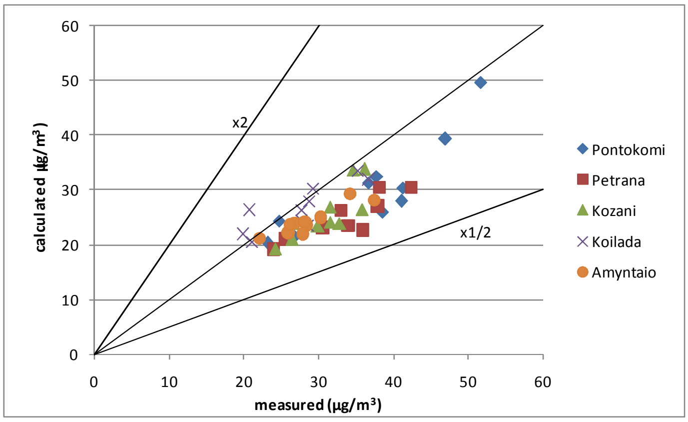

Figure 9. Comparison of calculated and measured average monthly PM_{10} concentrations

CONCLUSIONS

In the current study, the source-receptor relationships by using a dispersion model were investigated in Western Macedonia, a complex terrain area with large lignite power plants operation. One urban (Kozani), one residential – industrial (Pontokomi), three agricultural (Petrana, Amyntaio and K. Komi) and one industrial - agricultural (Koilada) areas were considered as receptors. The study covered a two years period, from 2009 to 2010, and employed the atmospheric dispersion model TAPM.

K. Komi was selected as background, since it is a distant station less affected by the industrial activities carried out in the basin. The Lignite Power Plants (LPPs) contribution to the PM_{10} concentration in each area was revealed by the Index of Agreement (IOA), between the mean monthly model predictions and the sum of the mean monthly sources contribution.

The highest LPP contribution to PM_{10} concentrations calculated by the IOA was recorded for Koilada (IOA=0.71) and the lowest for Petrana (IOA=0.39). These results were also confirmed by the calculation of the % LPPs contribution when the background was removed (84% for Koilada and 27% for Petrana). The contribution of LPPs in Pontokomi was also high (IOA=0.62, 58% LPPs contribution when the background was removed). However, it should be mentioned that the mean monthly PM_{10} concentrations and the modeled ones for Pontokomi were higher than Koilada. This was attributed to the position of the areas in the basin. In the case of Kozani, the IOA showed that LPPs are not the main PM_{10} sources (IOA=0.47). Actually, for Kozani, LPPs contribute to PM_{10} concentrations at an extent of 45%, with other sources being more important (e.g. traffic). As far as the agricultural Amyntaio and Petrana areas are concerned, these are less affected by LPPs (40% and 27%, respectively), and more influenced by other sources (e.g. agricultural activities). Both areas are placed at the boundaries of the basin. Amyntaio is a special case, since it comprises a temporal commercial junction. Actually, during November a large number of trucks with beets pass through Amyntaio, resulting at elevated measured PM_{10} concentrations. This was also revealed by the comparison between the measured and calculated PM_{10} concentrations for the same month.

Finally, for more accurate conclusions to be drawn, data corresponding to more than 2 years should be used. Aspects related to the uncertainties in the aforementioned calculations (emissions, background, land use etc) should also be considered. This is an ongoing activity in LAP-EP and more results will be published in the future.

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