SURFACE MINING IN WESTERN MACEDONIA, GREECE: PM10 EMISSIONS AND DISPERSION

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ABSTRACT

The operation of large open-pit lignite mines represents a significant source of fugitive dust emissions connected to energy production. In the process of extracting and handling excavation materials (overburden, lignite, waste material), a series of fugitive dust emission sources are recorded. The quantification of the emissions of each individual source and the investigation of atmospheric dispersion are subjects of great interest, because of the specificity of diffuse emission sources and the wide range of the particular characteristics of the excavation and handling materials. They constitute the foundation for the development and implementation of the environmental management and decision-making system that aims to avoid exceedance of air quality limits in the neighbouring residential areas. In this study, the contribution of the surface mining on the air environment of Western Macedonia, an industrial area in NW Greece, is investigated. Four open lignite mines (South field, Kardia, Mavropigi, Amyntaio) feed the lignite power plants operating in this area, contributing to the atmospheric pollution of the region. This study is referred to the PM10 emissions, emitted from the newer of the above mines (Mavropigi). Specifically, the percentage of the contribution of each individual activity – emission of fugitive dust over the period of one year is calculated. Furthermore, the dispersion of PM10 emitted from the whole mines operating in the area is simulated. For this purpose, emission factors were used that were calculated specifically for the mines of the Western Macedonia region in the context of the THEOPHRASTOS project, funded by the Lignite Centre of West Macedonia / Public Power Corporation SA. Specifically, the contribution of the individual PM10 emission sources recorded in the continuous and non-continuous extraction method was quantified and particularly by the following activities - PM emission of the Mavropigi mine: shovel excavation and loading, hauling and dumping, moving vehicles on unpaved haul road, bucket-wheel excavators, excavator's head, stacker head, multiple cross point. At the same time, there was an effort to investigate the dispersion of air pollutants emitted from each individual mine (South field, Kardia, Mavropigi, Amyntaio) and source activity and assess the contribution of the mining activities to the air quality of the surrounding areas, by using a three-dimensional, nestable, prognostic meteorological, and air pollution model. The results can contribute to the implementation of measures and scenarios for the air quality management in the area.

1 INTRODUCTION

Particulate Matter (PM) is a major pollutant in air environment of open cast lignite mines. Ambient air quality depends on emission sources and meteorological conditions. In an open-pit mine there co-exist fixed (e.g., power plants), mobile (e.g., trucks, bulldozers, etc.), and fugitive (e.g. loading and unloading of material) sources of emissions. It has been found that particulate matter from non-combustion sources is by far the main pollutant generated in an open-pit mine [1,2,3]. Its dispersion has been found to be a major concern in air quality modeling of open cast mines.

The basic step in looking at potential solutions to the air pollution problem is to quantify the mass of PM that are being emitted into the atmosphere and especially the investigation of the contribution into the whole PM emissions of each separately activity, such as topsoil and overburden removal, lignite extraction, transportation on haul road etc. On the other hand, the reliable quantification of the total pollutants emissions from the fugitive sources, is an obligation of the mining enterprises according to the 166/2006 Regulation [4], with a special emphasis on the contribution of each mining activity (excavation – transportation – deposition for barren, lignite and ash) to the total dust emissions and represents the first step in applying corresponding countermeasures.

The usual practice to quantify the mass of particulate material emitted into the atmosphere by activities inherent to open-pit mining is to estimate such emissions based on the emission factors recommended by the USEPA for this purpose [5,6]. However, there is a disagreement over the specific emission factors that must be used for each activity and the applicability of such factors to cases quite different to the ones under which they were obtained [7]. The quantification of dust emissions from open pits is strongly related to the exploitation method applied, the equipment used, the dust and other transported materials characteristics (e.g. silt content) as well as to the meteorological characteristic of the area. As a result, real data covering the area under study are necessary for a reliable calculation of dust emissions. The quantity of PM emitted from Mavropigi mine is calculated by using emission factors which have been developed for the specific mines of the area, in the frame of THEOPHRASTOS project [8]. This project was supported by Lignite Centre of Western Macedonia of Public Power Corporation of Greece and focused on the PM10 emission factors development of each mining activity (excavation, transportation, deposition for barren, lignite and ash). In summary, regarding the methodology applied, field measurements were conducted for all the main fugitive dust sources in the four open lignite mines in Western Macedonia, in “upwind-downwind” configuration. The data collected were used as input in Reverse Dispersion Modelling [9]. More details can be found in [10,11].

Finally, the dispersion of PM10 emitted from each individual source activity of the four mines in the area (South field, Kardia, Mavropigi, Amyntaio) and the contribution of the mining activities to the air quality of the surrounding areas are investigated, by using a three-dimensional, nestable, prognostic meteorological, and air pollution model.

2. MATERIALS AND METHOD

2.1. General Description of the Area

Lignite is an important energy source for Greece, contributing more than 50% (53.15%) of the country’s production in 2011, the reference year of this study. The most important lignite resources are in West Macedonia where four mines are in operation, constituting the Lignite Centre of Western Macedonia (LCWM) – the South Field, the Kardia Field, the Main Field (Mavropigi), and the Amyntaio mine (Fig.1). These are surface mines and operate using the German continuous mining method, i.e. with large electrical bucketwheel excavators, as the main extraction mean, conveyor belts for moving overburden, midburden and lignite, and stackers. There is also a large number of diesel powered equipment supporting the main installed electrical units. The annual production is around 50 million tonnes of lignite (2012). The remaining lignite reserves in West Macedonia are estimated to be 1.4 billion tonnes. Using current data, this is projected to lead to a potential closure of lignite mining at the West Macedonia PPC mines in 2050. Surface mining includes excavation, haulage, dumping of waste and pilling of lignite. The mining, hauling and dumping processes are significant sources of fugitive dust emission.

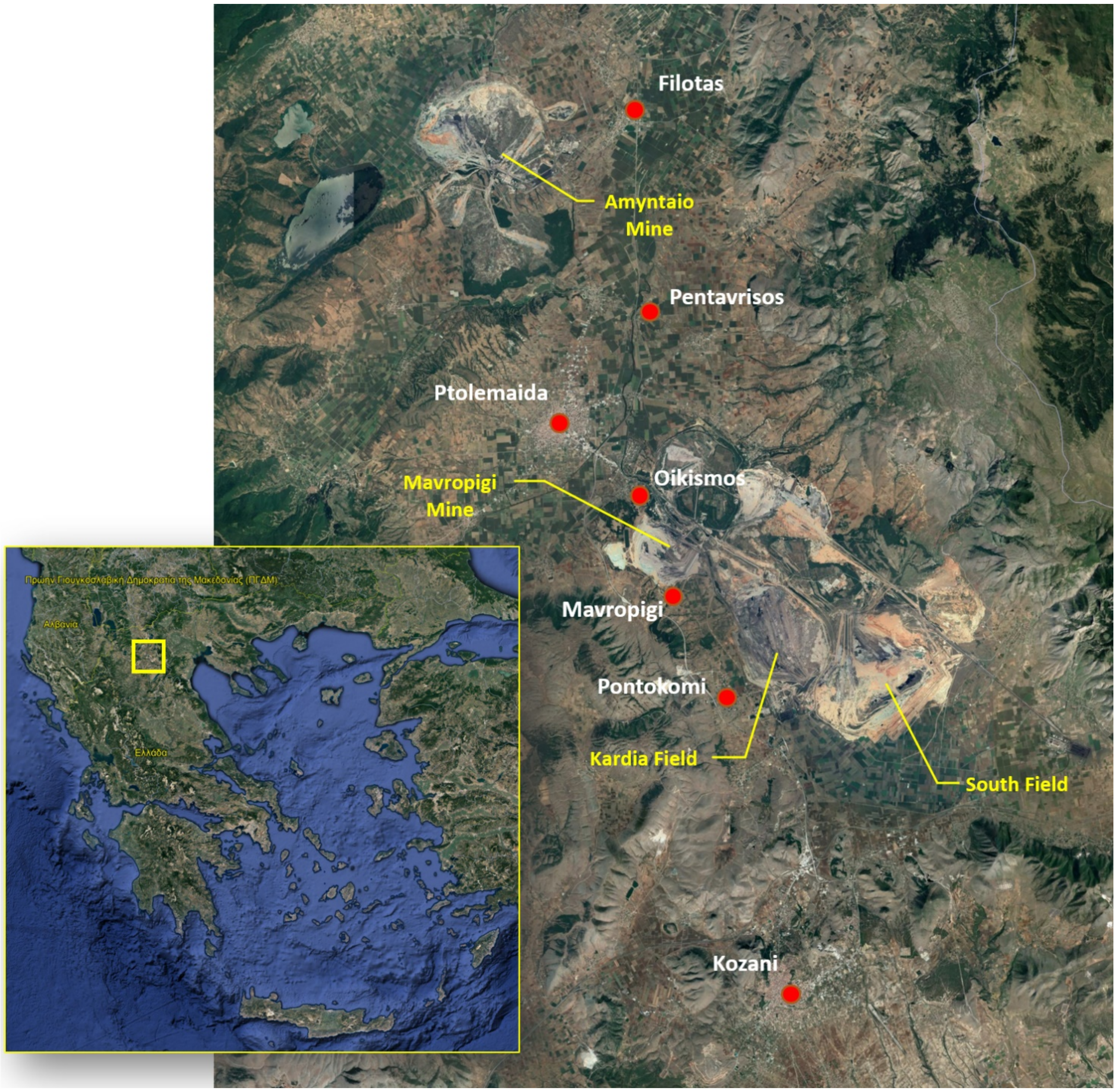

Figure 1. Map showing the opencast lignite mines of Western Macedonia, Greece. Kozani and Ptolemaida, the main towns in the area are also shown, as well as the locations of the receptors Pentavrisos, Oiksmos, Mavropigi, Pontokomi, where PM10 concentration measurements were taken.

2.2 Main PM Sources in the Mavropigi Mine

Two mining methods are used in the Mavropigi mine - the continuous (German) method, using bucketwheel excavators for mining, conveyor belts for hauling and stackers for dumping, and the truck and shovel method using large dumpers and trucks for hauling and dumping of material. These processes include the following sources of PM10 emission:

- Bucketwheel excavator mining (BE)
- Bucketwheel excavator head
- Stacker
- Stacker head
- Shovel excavation and truck loading
- Truck travel on gravel and dirt road
- Truck dumping
- Bunker
- Ash handling
- Complex

The individual source contribution to the total emissions was estimated for a period of one calendar year (2012).

2.3. Model Configuration, Data and Field Observations

The Air Pollution Model (TAPM) was used in this study. 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 quality assessment. 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. More information can be found in [12,13,14,15]

The model was applied for two periods of one month each, representing the cold and warm periods, respectively respectively, using 25 vertical model levels ranging from 10 m up to 8000 m, and four horizontally nested domains incorporating 37×37 horizontal grid points with a 30-, 10-, 3- and 1-km spacing for the meteorology, and 3-, 1-, 0.3- and 0.1-km spacing for the dispersion model, respectively (Fig. 2). NCEP synoptic analysis data were used to define the outer grid boundary conditions [12,13].

Figure 2. The four nested grids used for the simulation of meteorology.

The various PM10 emitting sources such as excavators, conveyor belts, excavator heads, complex, stackers, bunker, mining, hauling and dumping contractors, and equipment movement on dirt roads, were considered as linear, surface or volume sources for the simulation of mining, hauling and dumping sources of PM10 emission (Fig.3). As already mentioned, for each one of the above sources, emission factors have been used as they were calculated under the framework of project THEOFRASTOS of the LCWM [10]. This calculation was performed in conjunction with concentration measurements "upwind – downwind" of each source and reverse dispersion modelling [9].

In the following, we assume a 24-hour operation of the continuous mining equipment and 10-hour operation of the activities-sources of non-continuous mining, as a worst-case scenario. Once the activity parameters were defined, the topography of the area in high resolution (90m, STRM3) was imported to the model. TAPM evaluation was performed by producing PM10 concentrations forecasts in six selected sites-receptors located in Pentavrisos, Ptolemaida, Oikismos DEH (PPC), Mavropigi, Pontokomi, and Kozani.

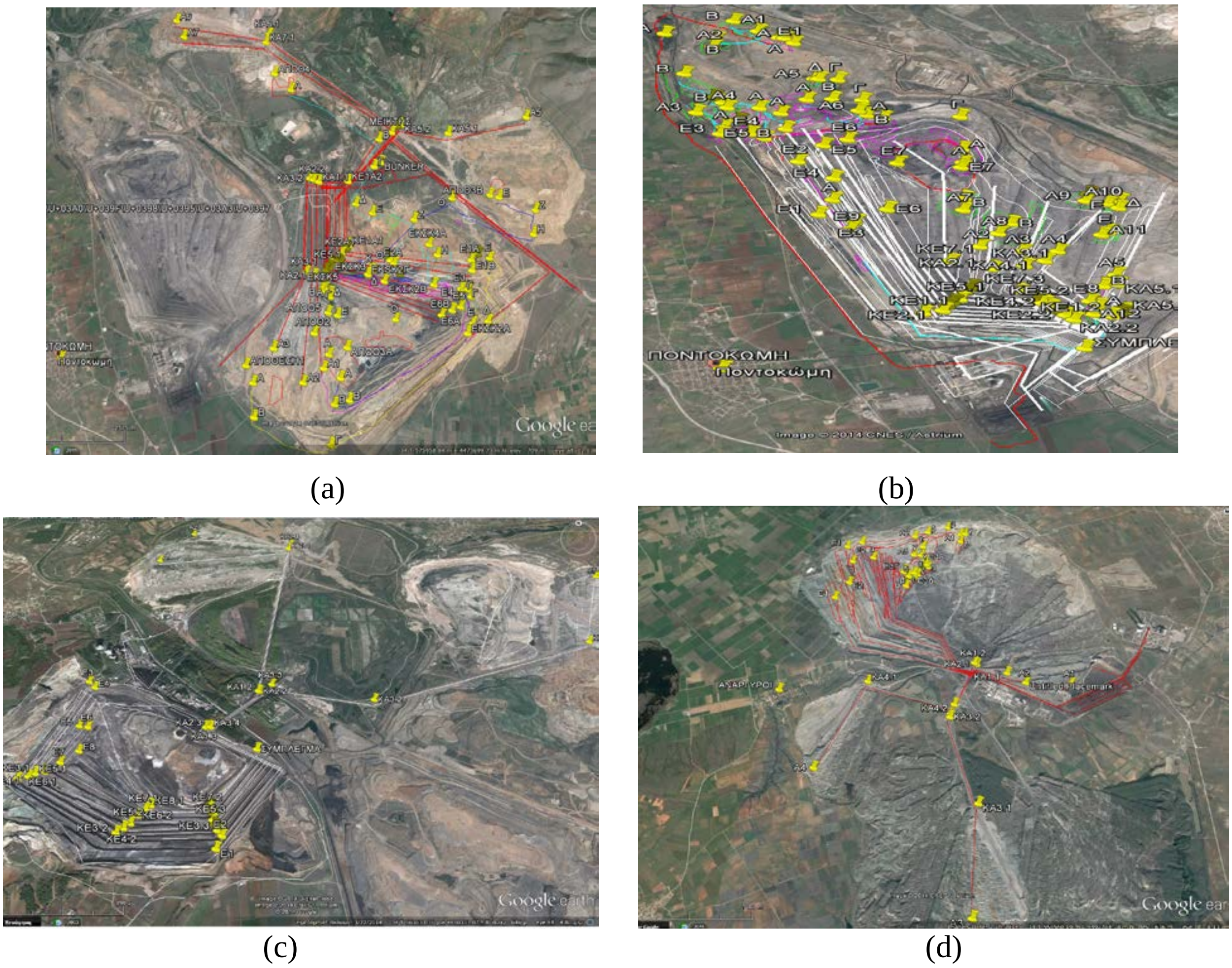

Figure 3. Locations of PM10,linear, surface and volume sources (excavators, conveyor belts, excavator heads, compelx, stackers, bunker, mining, hauling and dumping contractors, equipment movement) digitised for the simulation of (a) South Field, (b) Kardia Field, (c) Main Field (Mavropigi Mine), (d) Amynatio Mine.

For the dispersion simulation, the month of the hot period with the highest average monthly concentration was chosen. Figure 4 shows the average monthly concentration of PM10 at the Western Macedonia basin in 2012, from measurements of PPC and TEIWM. It is evident that July is the month with the highest average monthly concentration.

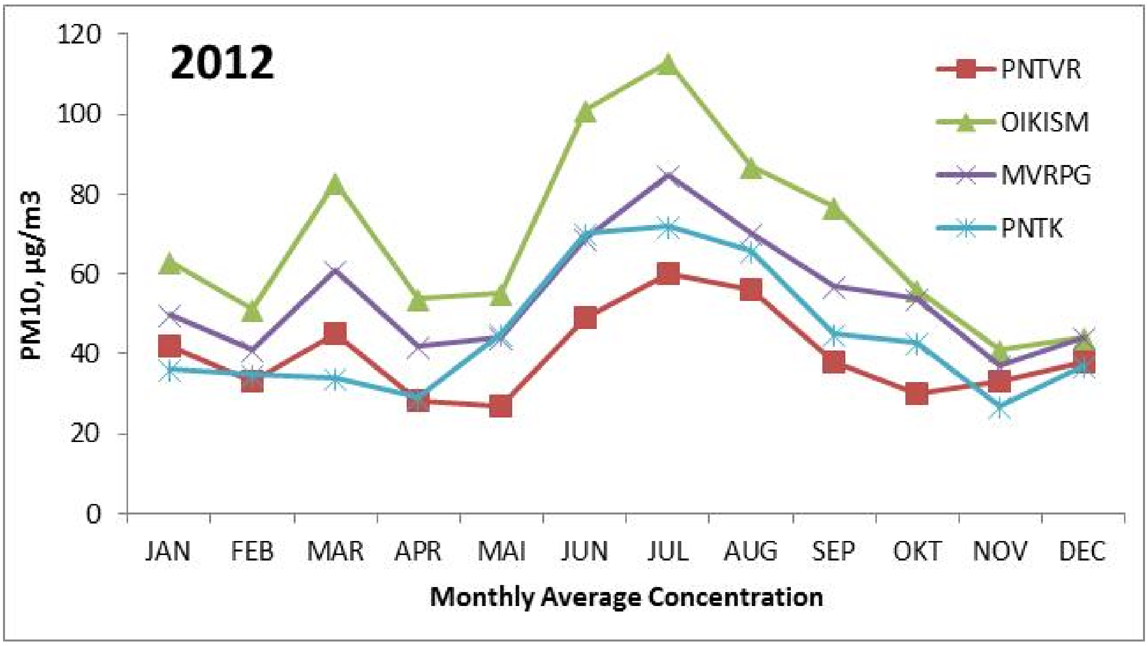

Figure 4. Average monthly PM10 concentration at the receptors near the Mavropigi mine in 2012 (PPC measurements).

A month of the cold period, January 2013, was chosen respectively. Figure 5 shows wind rose diagrams at the Pontokomi receptor, approximately 5.5 km SE of the Mavropigi mine limits, for each of the simulation months.

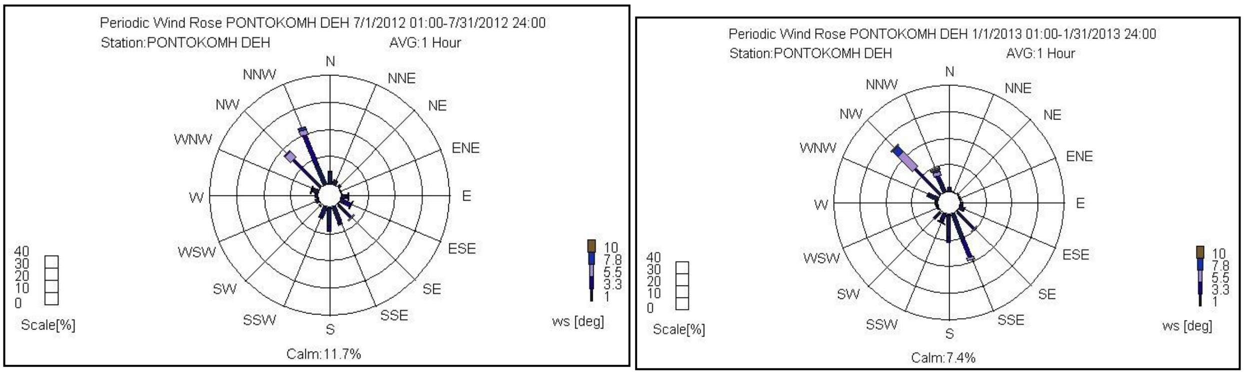

Figure 5. Wind rose diagrams from the Pontokomi receptor for the simulation months, i.e. June 2012 (left) and January 2013 (right).

The wind direction in both months is from the NW being strongest in January. The highest percentages of calms were found in July.

3 RESULTS AND DISCUSSION

3.1. Emissions Calculation

The following mining activity parameters were used, provided by LCWM.

Table 1. Mavropigi mine operational parameters for the period 01/2012 – 12/2012.

Parameter	Quantity	Units
Waste removal	84952667	t
Lignite mining	5888469	t
Ash quantities moved	988085	t
Strip ratio	7.4	m^3/t
Waste specific gravity	1.95	t/m^3
Ash specific gravity	0.85	t/m^3
Lignite specific gravity	1.23	t/m^3
Truck capacity for compact material	14	m^3
Waste quantity hauled with trucks	38466979	T
Lignite quantity hauled with trucks on asphalt road	3226647	T
Ash handler operation hours	3364	T
Lignite quantity hauled on dirt road	3226647	T
Lignite conveyor belt travel length	3.7	Km
Waste conveyor belt travel length	2.46	Km
Stackers operation hours for mixed material	12799	h
Stacker heads number	8	
Excavator operation hours for lignite	2352	h
Excavator operation hours for waste	24861	h
Lignite excavator heads number	16	

Figure 6 presents in pie chart format the percentages of contribution for each activity to the total emission of escaping dust from the Mavropigi mine for 2012.

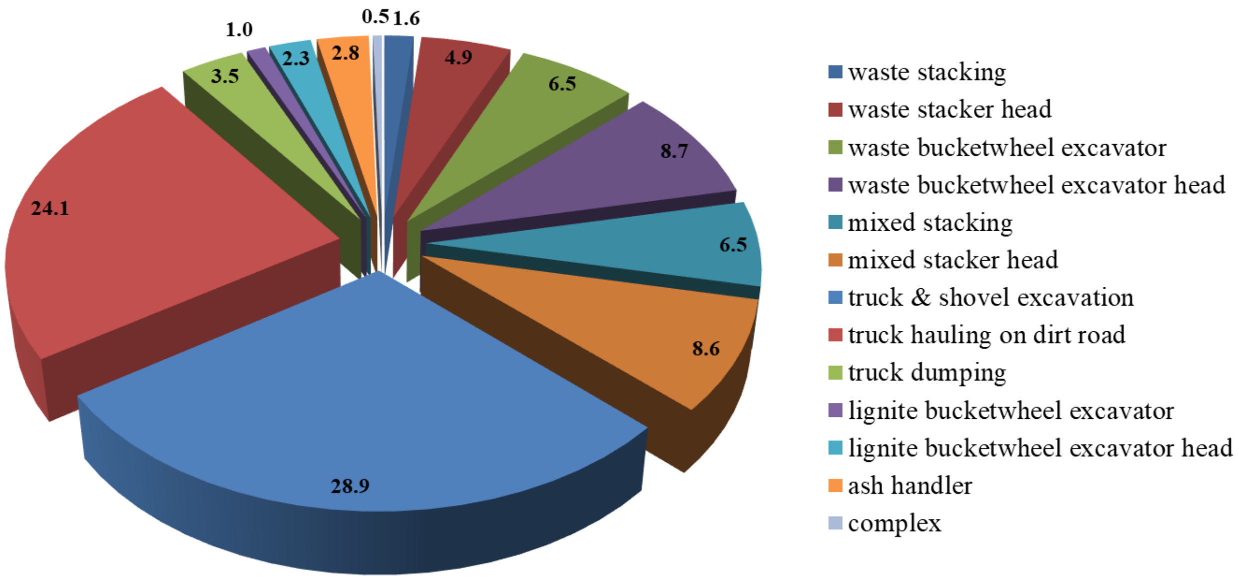

Figure 6. Contribution of each activity at the Mavropigi mine to the total escaping dust emissions of the mine during the period 01/2012 – 12/2012.

The total emissions are distributed to the individual activities as follows:

- Shovel excavation and truck loading (28.87%),
- Truck hauling on dirt road (24.11%),
- Bucketwheel excavator head – waste mining (8.69%),
- Stacker head – mixed (8.59%),
- Bucketwheel excavator – waste mining (6.54%),
- Stacking – mixed (6.54%),
- Stacker head – waste (4.92%),
- Truck dumping (3.50%),
- Bucketwheel excavator head – lignite (2.30%),
- Ash handling (2.82%),
- Stacking – waste (1.58%),
- Bucketwheel excavator – lignite mining (1.04%),
- Complex (0.49%) and
- bunker (0.01%).

The maximum PM10 contribution to the total mine emissions are from the activities related to truck & shovel excavation and loading, and truck hauling on dirt roads.

3.2. Dispersion

Figures 7a and 7b show PM10 pollution contours for per month as derived through simulations. They present the average monthly levels of PM10 concentrations produced by the emissions of the three mines (South, Kardia and Mavropigi) for the studied worst-case scenario.

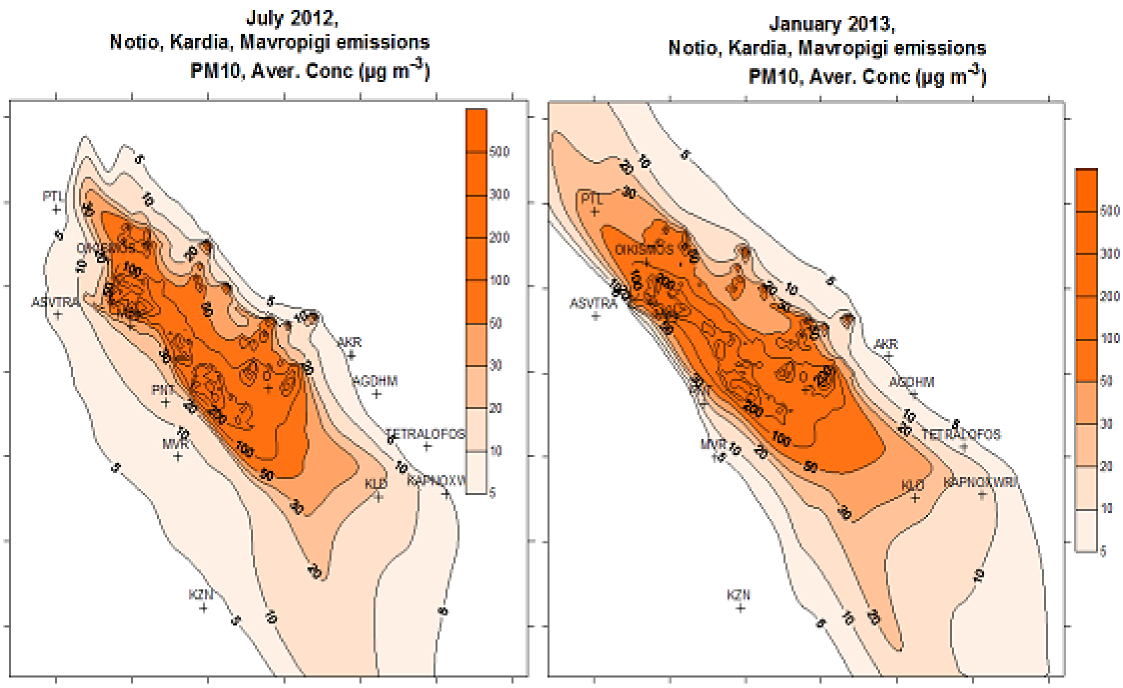

Figure 7. PM10 pollution contours due to emissions from the Mavropigi, Kardia and South Field mines in July 2012 (left) and January 2013 (right).

The higher dispersion and transport of PM10 at greater distances during the cold period is characteristic of the prevailing conditions of that period, namely stronger winds and a more shallow mixing layer.

In Table 2, second row (Measured Average - MA), the average PM10 concentrations of the simulation period, as measured at the stations are given. Row three shows the corresponding values obtained from the simulations (Simulation Average - SA), i.e. the PM10 concentration contribution at the respective receptor attributed to the mines' (Amyntaio, Mavropigi, Kardia and South Field) emissions, according to the studied worst-case scenario. Row four shows the PM10 concentration contributed by the mines for the operation data considered in the simulation, as a percentage of the measured concentration at the same period and receptor (Overestimated Mine Contribution %, OMC%).

It is noted that the concentrations at the receptors due to mine emissions, and thus the mines contribution percentage (row four in the table) refer to the scenario of mines operation considered, while the measured values correspond to the actual mines operation. For a more accurate estimation of the mines contribution, we define some indicators of mines influence in the range of 0 to 10. By setting the value of 10 to the Oikismos area receptor, where the highest concentrations were measured (73 μg/m^3), as well as the highest mines influence (70 μg/m^3), we define three indicators:

1. The **Relative Indicator of Measured PM10 concentrations (RIMPM10)** from all sources. It rescales the measured PM10 concentrations at each receptor to a standard scale of 0-10 with reference to the concentrations measured at Oikismos.
2. The **Relative Indicator of Calculated PM10 concentrations (RIMP10C)** for the contribution due to the mines emissions. It rescales the calculated PM10 concentrations at each receptor to a scale of 0-10, relative to the concentrations calculated for Oikismos.
3. The **Overestimated Relative Indicator of Mines Influence (ORIMI)**. It rescales the relative influence of the mines from their operation as a percentage of the measured concentrations to a standard scale of 0–10, with the highest value assigned for Oikismos (10).

This way all three indicators can be presented in a scale of 0 to 10, where the value of 10 was set at Oikismos. In rows 5, 6 and 7 of Table 2, the indicator values for Pentavrisos, Ptolemaida, Oikismos, Mavropigi, Pontokomi and Kozani are presented.

Table 2. Observed, predicted PM10 concentrations and contribution indicators of surface mining PM10 emissions

1	Receptor	Pentavrisos	Ptolemaida	Oikismos	Mavropigi	Pontokomi	Kozani
2	MA (μg/m^3)	45	58	73	57	38	29
3	SA (μg/m^3)	12	32	70	48	14	3
4	OMC%	27	55	96	84	38	10
5	RIMPM10	6.2	7.9	10.0	7.8	5.2	3.7
6	RIMPM10C	1.7	4.6	10.0	6.9	2.0	0.4
7	ORIMI	2.8	5.7	10.0	8.7	3.9	1.0

The above values are shown graphically in Fig. 8. It is evident that Ptolemaida has equal or slightly higher PM10 concentration indicator value than Mavropigi, but the later has much higher mining contribution indicator value.

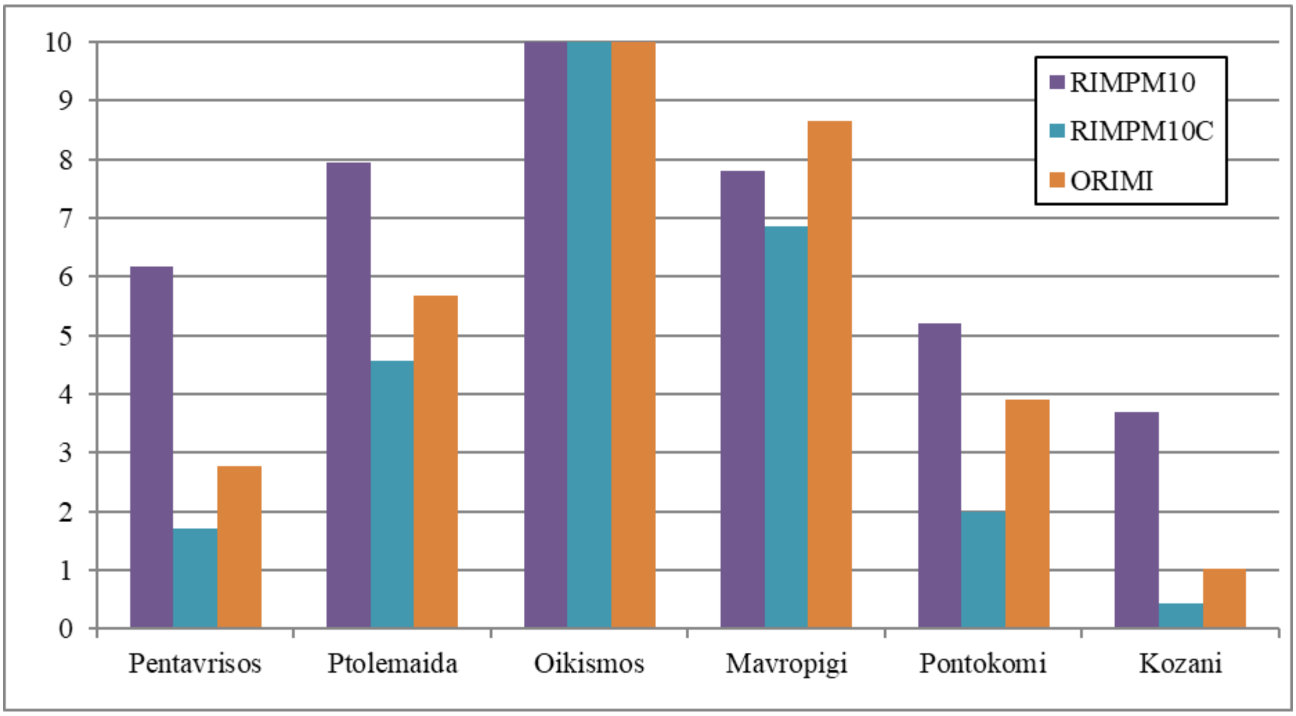

Figure 8. Surface mining contribution indicators on atmospheric pollution of specific receptors, computed by using observed and predicted (worst case scenario) PM10 concentration.

The above analysis refers to two-month average values, on in the hot period and one in the cold. One should note the very wide range of average daily concentrations at the receptors, particularly those closer to the PM emitting activities.

4 CONCLUSIONS

More than 50% of the total annual PM10 emitted mass from a specific surface lignite mine (Mavropigi) in Western Macedonia was produced by activities related to non-continuous mining and specifically from truck & shovel excavation and loading, and truck hauling on dirt roads. The relative indicator of PM10 concentration measurements, as they were taken at receptors and were caused by all PM10 emission sources in the area, the relative indicator of measured PM10 calculated concentrations as they were calculated from simulations and are caused only by the mines' (South field, Kardia, Mavropigi, Amyntaio) dust emissions, and the overestimated relative indicator of mines' influence, are useful tools for the assessment of the relative contribution of the fugitive dust emissions on the PM10 concentrations measured at the selected receptors in the area. Finally, it is possible to design and implement an integrated system for the management of the various mining activities, incorporating an operational module for the forecasting of their contribution to the PM10 concentration levels at selected receptors, aiming at the improvement of air quality in the area affected by the operation of the surface mines.

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