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Environmental Effects of the Open Cast Mining a Case Study: Irbid Area, North Jordan

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Abstract

Jordan has huge limestone reserves which are used to produce aggregates for construction purposes. These reserves are very important economic sectors in Jordan, but many of these reserves belong to quarries that are located near urban territories. The mining operation type is mainly open cast and this activity has fugitive dust sources that contribute to increasing air quality levels in the urban areas around the quarries. Many of the biggest quarries in Jordan surrounded with urban territories are located in the north of Jordan district Irbid (Sammad area). Due to the quarrying activities, especially those from limestone quarrying (e.g. drilling and blasting, excavation, and transportation) in North Irbid, it is noticed that there is a primary source of an increased level of particulate matter (PM10), which leads to a potential representing pollution to the surrounding areas. PM consists of very small liquid and solid particles floating in the air with a diameter less than 10 microns that are subject to be inhaled into the deepest parts of the lung, and subsequently cause harmful health problems for population. PM10 dust re-suspension factors of the surrounding areas near the limestone quarries close to Sammad area/Irbid province were measured for different seasons at two station areas: Shatana and Rahma. To obtain data and assessment of the impact from this source, measurements included PM10 mass, particle size distributions, wind speed, and wind direction. The results showed that PM10 concentrations could be as high as 130 μg/m^3, and that most of the airborne PM was in the coarse fraction. The results revealed that in winter season during the workday, the concentration of PM10 was equal to or below the Jordanian standard, while in summer season during workday the concentration of PM10 was over the Jordanian standard. However, forward trajectories showed that pollutants were attributed to the mining activities inside the quarries and distributed outside the mining area surrounding with urban territories.

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Keywords

Jordan, Limestone, Open Cast Mining, Aggregate, Particulate Matter (PM10), Airborne PM

1. Introduction

Limestone in Jordan has a broad distribution, occurs in different stratigraphic levels with several meters of thickness, and presents with huge reserves in many parts of the country as shown in **Figure 1**. It is used for construction of composite wall for aesthetic purposes, such as thin polished tiles (marble), floor tiles and monumental architecture or dry stonewalling that characterizes the countryside of Jordan buildings, in addition to its uses as aggregates [1]. The limestone production is a very important economic sector in Jordan [2]. The limestone production in Jordan is shown in **Figure 2**. Many of the limestones belong to the quarries that are located near to urban territories in the Irbid district (Sammad area), north of Jordan. Most of the mining operation is mainly open cast mining. The mining activities emit air pollutants such as particulate matter (PM) into the air through different sources and emissions. The mining activities have fugitive dust sources that contribute to increasing air quality levels in the urban areas around the quarries. Most of the limestone aggregates are a mixture of grains resulting from fragmentation of rocks due to crushing and milling industry by different machines that can be subdivided into two types: coarse aggregates and fine aggregates (microns to few mm).

The authorities in Jordan are developing air quality plans to bring PM10 concentrations down to healthful levels. These plans include a variety of regulations and programs to reduce emissions, including dust control for transport, mines and quarries through using PM10 and PM2.5 [3] [4]. The Jordanian Standards of Ambient Air

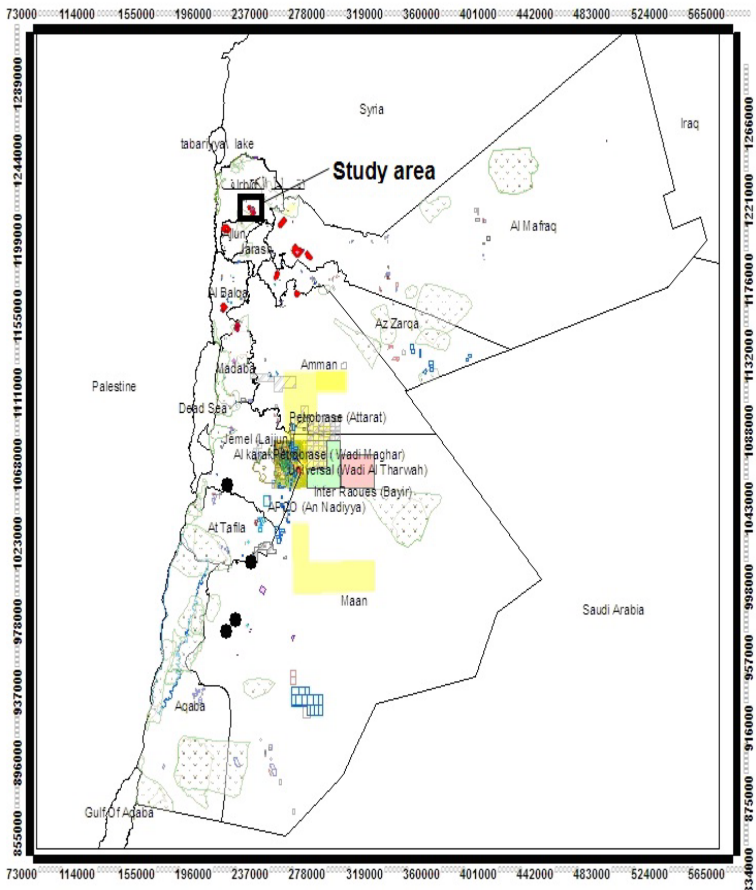


Figure 1. The location of quarries in Jordan and the study area.

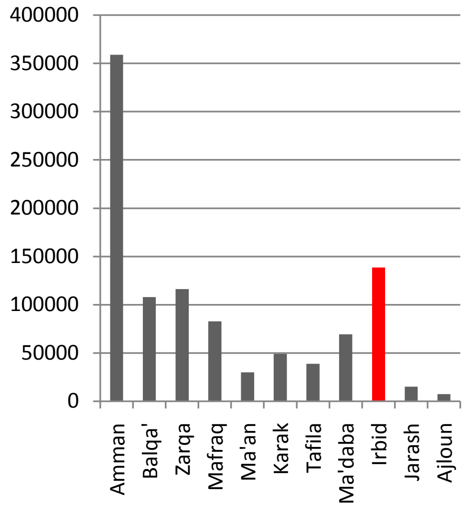


Figure 2. The limestone aggregate production from different areas in Jordan including Irbid area.

Quality (JSAAQ) including the standard of PM10 was used in this study. Regarding to this standard, the maximum allowable concentration of PM10 for duration of 24 hours is up to 120 µg/m^3, and annually is up to 70 µg/m^3.

Airborne particulate matter represents one of the most pollutant factors in quarrying activities. PM10 pollution consists of very small liquid and solid particles floating in the air. Of greatest concern to public health are the particles small enough to be inhaled into the deepest parts of the lung. These particles are less than 10 microns in diameter and are known as PM10. This includes fine particulate matter known as PM2.5. PM10 is a major component of air pollution that threatens both our health and our environment. PM10 can increase the number and severity of asthma attacks, cause or aggravate bronchitis and other lung diseases, and reduce the body's ability to fight infections [5]-[12]. Of greatest concern are recent studies that link PM10 exposure to the premature death of people who already have heart and lung disease, especially the elderly [13] [14].

Many areas in Jordan suffer from elevated levels of PM10. One potentially significant source of the observed PM10 is the resuspension of road dust and dust causes by mining activities in the vicinity of limestone quarries as shown in **Figure 3**. This is a problem in our cities, rural areas and pristine areas such as national parks, forests and vegetation. Amount of 150.000 ton of limestones and aggregates are exploited from these areas and most of the quarries are scattered throughout the urban areas. Their exploration, excavation, and mineral processing directly infringe upon and affect the other natural resources like land, water, air, flora and fauna, which are to be conserved and optimally utilized in a sustainable manner. The environmental problems associated with limestone quarrying and mining are diverse. The removal of vegetation and topsoil and increasing of overburden and waste will affect the landscape of these areas.

To obtain data and to assess the impact from these sources, PM10 road dust resuspension factors near Sammad, SW Irbid were measured. Measurements included PM10 mass, particle size distributions, wind speed, wind direction and rainfall. After the results were presented, the conclusions discussed the state of PM10 concentration regarding the Jordanian Ambeint Air quality Standard (JS-1140/2006) through the measured period from January 2009 to November 2009.

2. Methodology

The methodology adopted in this study is based on the specific parameters through the period from January 2009 to November 2009. The domain of the present analysis covers all the limestone quarries area and the most important urban areas around them. The data of information of the air quality of PM10 have been taken from Mobile station which belongs to Natural Resources Authority (NRA). The meteorological information has been used based on data of Yarmook University station and Ras Munif. The emission inventories were based on the EPA AP-42 emission factors [15], and the amount of activities were reported by the NRA and mining companies. Based on these data the following activities have been carried out:

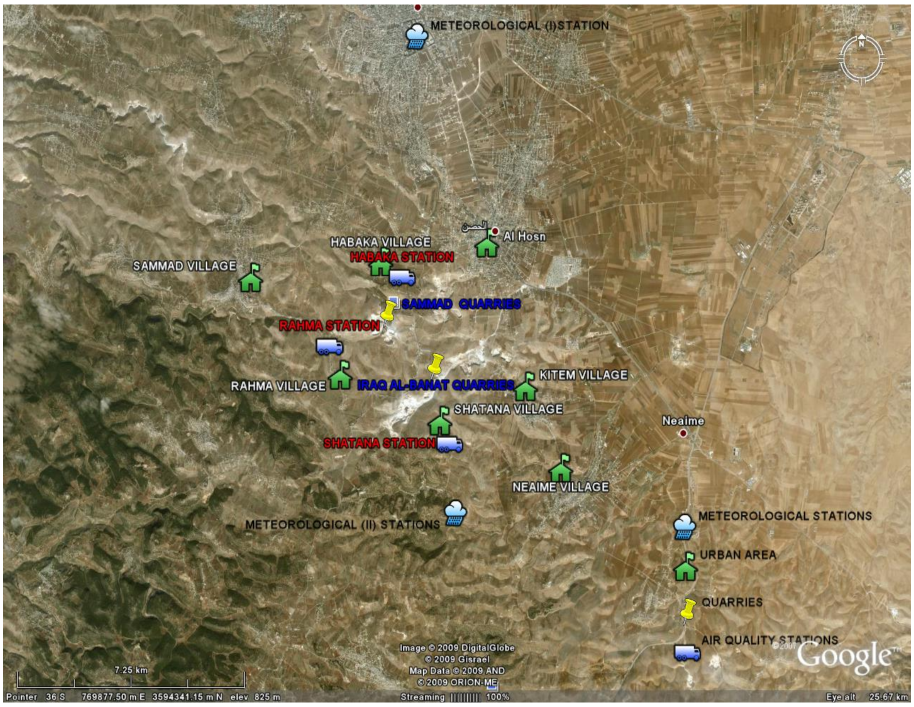


Figure 3. Limestone quarries locations, the urban areas around them. Air quality PM10 mobile stations and meteorological stations in Irbid/Jordan.

- Comparing the measured concentrations of PM10 with the Jordanian standard.
- To prepare analysis of trends and correlation between air quality and meteorological stations.
- Using avilable dispersion models for Sammad area (Shatana and Rahma), then applying the results at the similar areas.
- Setting up an air quality dispersion model for some of the mining areas in Jordan and comparing of the calculated and measured concentrations.
- Analyzing and discussing the given results.
- Methods of mitigation and recommendation

3. Results and Discussion

3.1. Comparing the Measured Concentration of PM10 with the Jordanian Standard

To follow up the the measured concentration of PM10 in the study area it was considered to compare our results with the Jordanian Ambeint Air quality Standard (JS-1140/2006). The results are discussed for both areas Shatana and Rahma.

3.1.1. First Area Station (Shatana)

The maximum value of PM10 was 110 µg/m^3 during July, and the minimum value was 50 µg/m^3 during June as shown in **Table 1**. During summer season (June-Aug.) The range of PM10 value was (120 - 140 µg/m^3), and the value of PM10 during other seasons was around the Jordanian standard as shown in **Figure 4**, **Figure 5** and **Table 1**.

During the measured period the concentration of PM10 was below the Jordanian standard except the period from (Jun.-Aug.) as shown in **Figure 6**.

3.1.2. Second Area Station (Rahma)

During the period from (Jan.-Jun.) the concentration of PM10 was below the Jordanian standard, but during the period from (Jun.-Nov.) the concentration of PM10 was above the Jordanian standard as shown in **Table 2** and **Figure 7**.

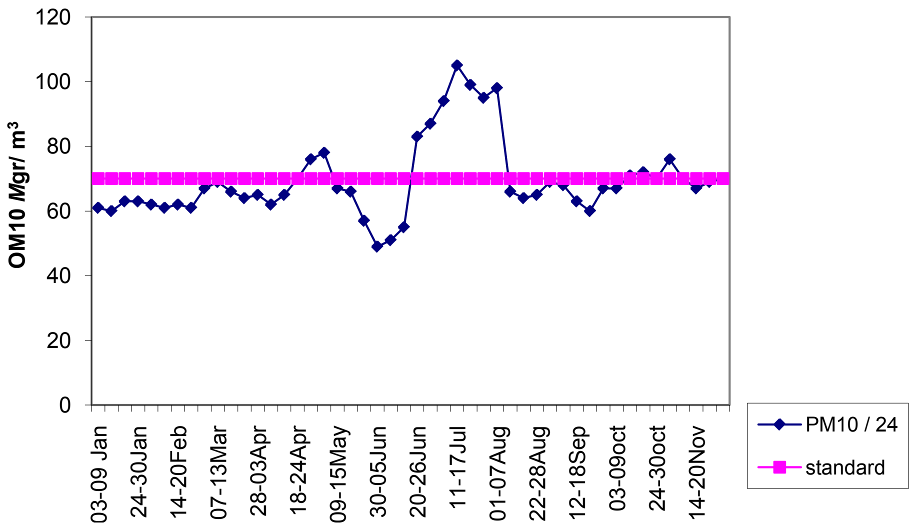


Figure 4. Comparing the measured concentrations of PM10 with the Jordanian standard at first station area (Shatana) for 24 hours.

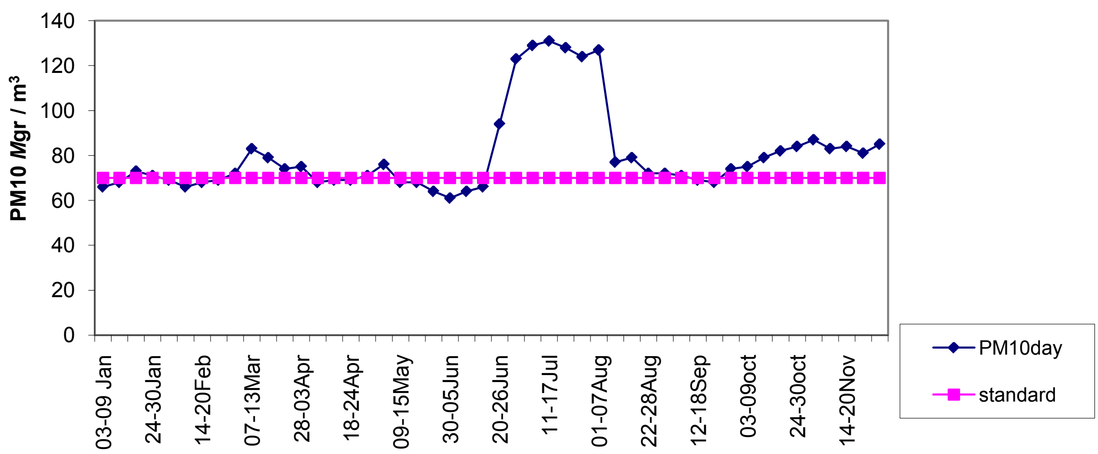


Figure 5. Comparing the measured concentrations of PM10 with the Jordanian standard at first station area (Shatana) for day work.

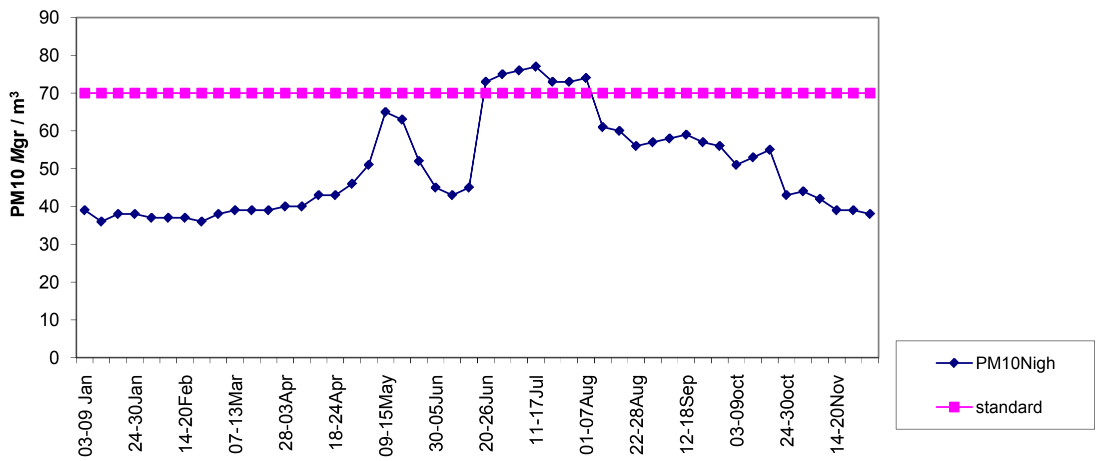


Figure 6. Comparing the measured concentrations of PM10 with the Jordanian standard at first station area (Shatana) at night.

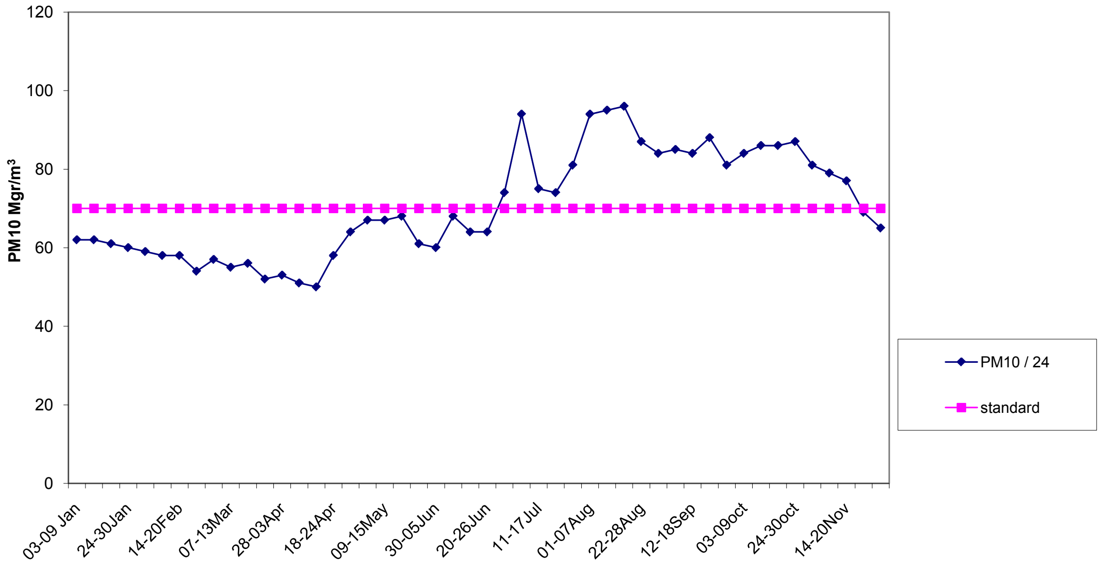


Figure 7. Comparing the measured concentrations of PM10 with the Jordanian standard at second station area (Rahma) for 24 hours.

Table 1. Value of PM10 during the period from 3 Jan. to 28 Dec. 2009 at Shatana area.

Shatana area				
Date	**PM10 day**	**PM10 night**	**PM10/24 h**	**Standard**
03-09 Jan.	66	39	61	70
10-16 Jan.	68	36	60	70
17-23 Jan.	73	38	63	70
24-30 Jan.	71	38	63	70
01-06 Feb.	69	37	62	70
07-13 Feb.	66	37	61	70
14-20 Feb.	68	37	62	70
21-27 Feb.	69	36	61	70
28-06 Mar.	72	38	67	70
07-13 Mar.	83	39	69	70
14-20 Mar.	79	39	66	70
21-27 Mar.	74	39	64	70
28-03 Apr.	75	40	65	70
04-10 Apr.	68	40	62	70
11-17 Apr.	69	43	65	70
18-24 Apr.	69	43	70	70
25-01 May	71	46	76	70
02-08 May	76	51	78	70
09-15 May	68	65	67	70
16-22 May	68	63	66	70

Continued

23-29 May	64	52	57	70
30-05 Jun.	61	45	49	70
06-12Jun.	64	43	51	70
13-19 Jun.	66	45	55	70
20-26 Jun.	94	73	83	70
27-03 Jul.	123	75	87	70
04-10 Jul.	129	76	94	70
11-17 Jul.	131	77	105	70
18-24 Jul.	128	73	99	70
25-31 Jul.	124	73	95	70
01-07 Aug.	127	74	98	70
08-14 Aug.	77	61	66	70
15-21 Aug.	79	60	64	70
22-28 Aug.	72	56	65	70
29-04 Sep.	72	57	69	70
05-11 Sep.	71	58	68	70
12-18 Sep.	69	59	63	70
19-25 Sep.	68	57	60	70
26-02 Oct.	74	56	67	70
03-09 Oct.	75	51	67	70
10-16 Oct.	79	53	71	70
17-23 Oct.	82	55	72	70
24-30 Oct.	84	43	70	70
31-06 Nov.	87	44	76	70
07-13 Nov.	83	42	70	70
14-20 Nov.	84	39	67	70
21-27 Nov.	81	39	69	70
28-04 Dec.	85	38	70	70

Table 2. Value of PM10 during the period from 3 Jan. to 28 Dec. 2009 at Rahma area.

Rahma area				
Date	**PM10 day**	**PM10 night**	**PM10/24 h**	**Standard**
03-09 Jan.	65	32	62	70
10-16 Jan.	65	34	62	70
17-23 Jan.	64	30	61	70
24-30 Jan.	61	32	60	70
01-06 Feb.	60	30	59	70

Continued

07-13 Feb.	61	30	58	70
14-20 Feb.	60	27	58	70
21-27 Feb.	62	28	54	70
28-06 Mar.	61	28	57	70
07-13 Mar.	60	29	55	70
14-20 Mar.	61	30	56	70
21-27 Mar.	63	30	52	70
28-03 Apr.	63	31	53	70
04-10 Apr.	61	31	51	70
11-17 Apr.	69	35	50	70
18-24 Apr.	69	34	58	70
25-01 May	72	35	64	70
02-08 May	76	33	67	70
09-15 May	79	36	67	70
16-22 May	78	35	68	70
23-29 May	81	35	61	70
30-05 Jun.	84	36	60	70
06-12 Jun.	86	34	68	70
13-19 Jun.	88	39	64	70
20-26 Jun.	97	39	64	70
27-03 Jul.	138	45	74	70
04-10 Jul.	148	48	94	70
11-17 Jul.	148	49	75	70
18-24 Jul.	142	48	74	70
25-31 Jul.	151	50	81	70
01-07 Aug.	167	51	94	70
08-14 Aug.	164	56	95	70
15-21Aug.	169	55	96	70
22-28 Aug.	175	55	87	70
29-04 Sep.	161	52	84	70
05-11 Sep.	168	58	85	70
12-18 Sep.	151	54	84	70
19-25 Sep.	164	51	88	70
26-02 Oct.	169	49	81	70
03-09 Oct.	174	50	84	70
10-16 Oct.	170	48	86	70
17-23 Oct.	167	48	86	70
24-30 Oct.	150	46	87	70
31-06 Nov.	143	44	81	70
07-13 Nov.	121	47	79	70
14-20 Nov.	106	44	77	70
21-27 Nov.	88	34	69	70
28-04 Dec.	71	33	65	70

During the period from (Jan.-Apr.) the concentration of PM10 was below the Jordanian standard, but during the period from (Apr.-Nov.) the concentration of PM10 was above the Jordanian standard as shown in **Figure 8**.

During the measured period at night the concentration of PM10 was below the Jordanian standard as shown in **Figure 9**.

3.2. Correlations between Meteorological and Air Quality Data

3.2.1. Wind Roses

According to Jordan Meteorology Department, the wind roses for the study area (Sammad limestone mining area) are as shown in **Figure 10**.

3.2.2. Trajectory Plot of the Maximum Wind Speed

By using NOAA HYSPLIT MODEL, the result of the forward trajectories have shown that pollutants attributed to the mining activities inside the quarries, and distributed outside the mining area as shown in **Figure 11** and **Figure 12**. The trend of the wind is mostly toward east and to the southeast. **Figure 12** shows the trajectory plots of the particle positions at the day of 18 Jul. 2009.

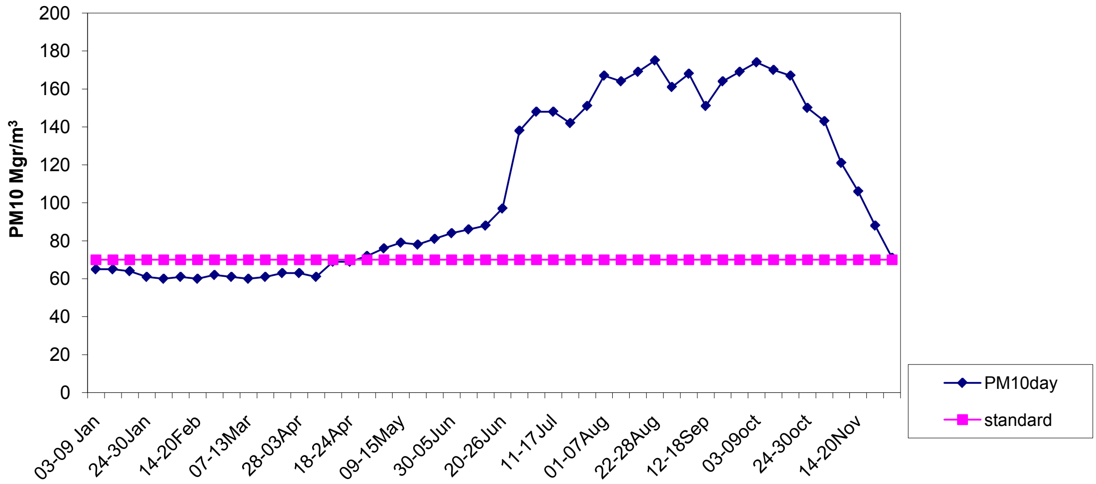


Figure 8. Comparing the measured concentrations of PM10 with the Jordanian standard at second station area (Rahma) for day work.

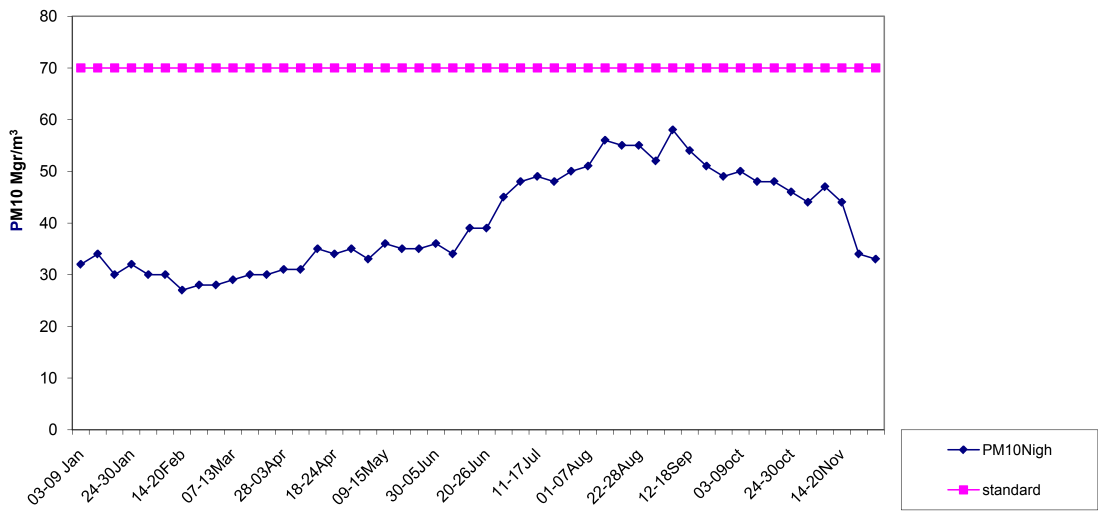


Figure 9. Comparing the measured concentrations of PM10 with the Jordanian standard at second station area (Rahma) at night.

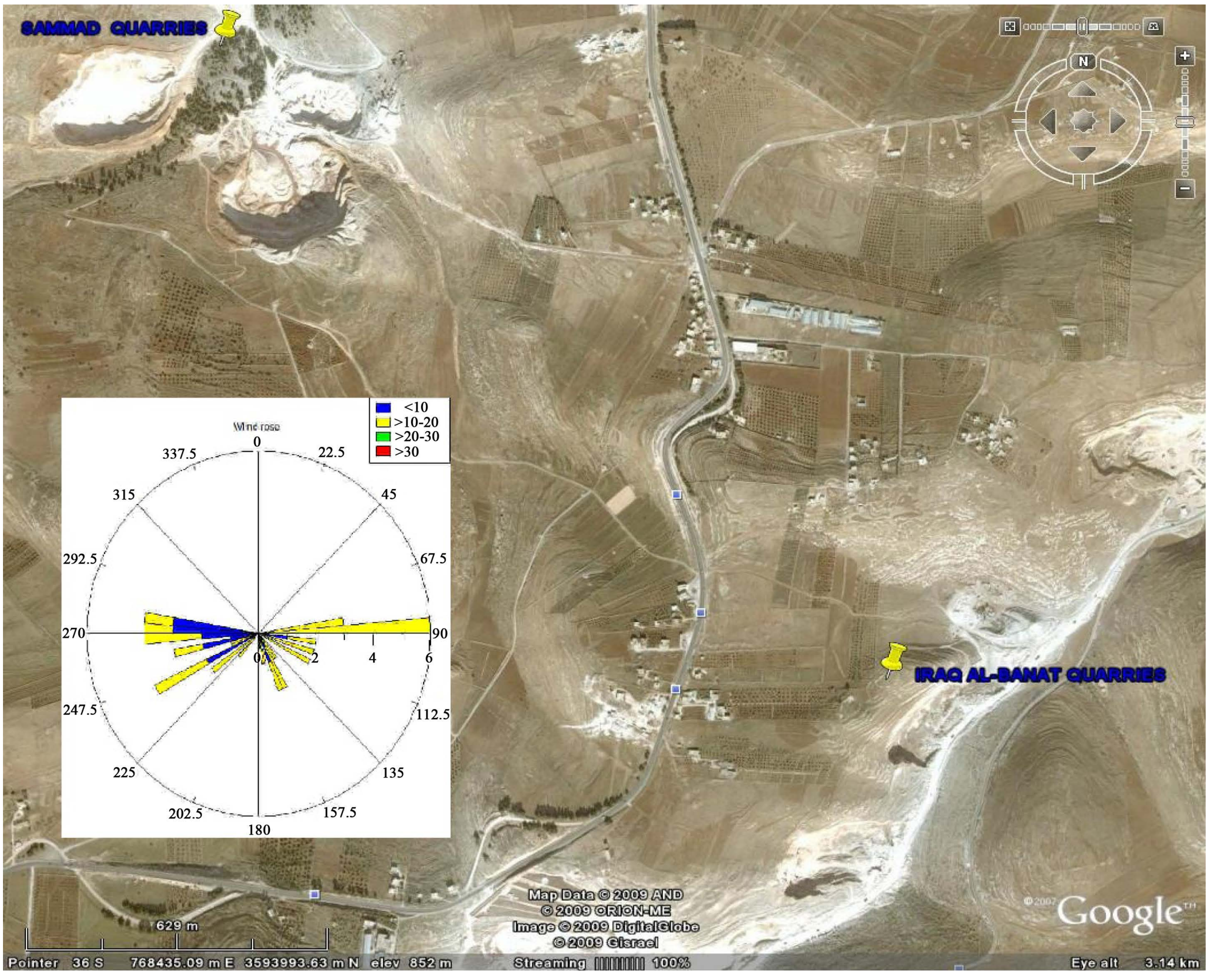
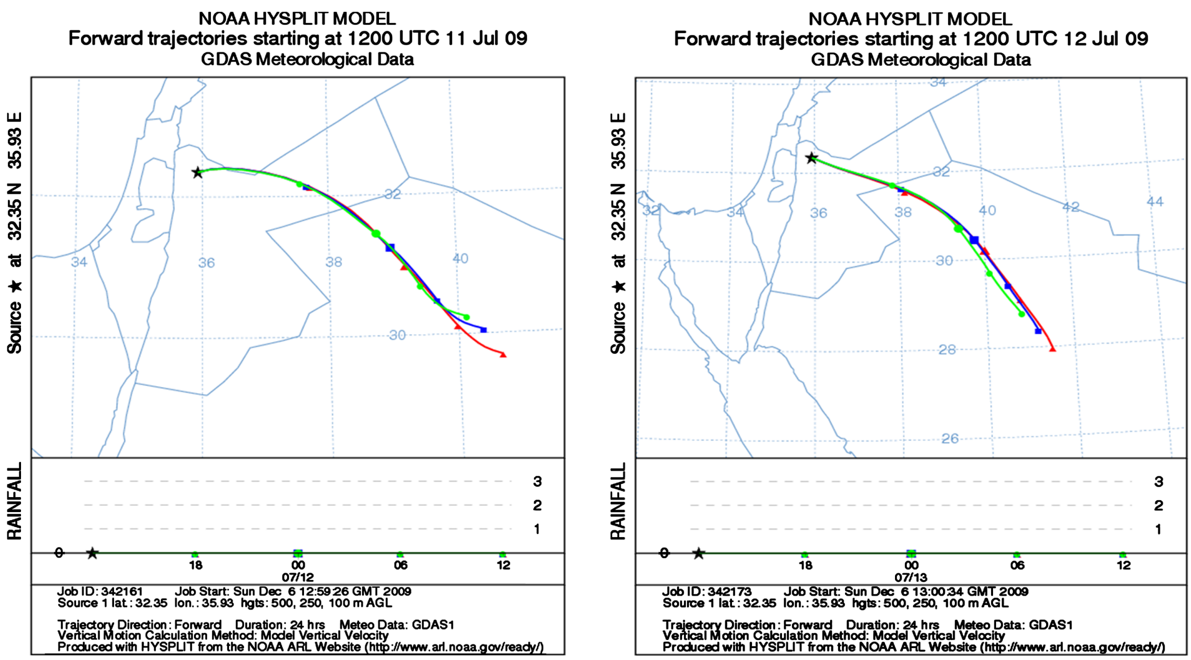
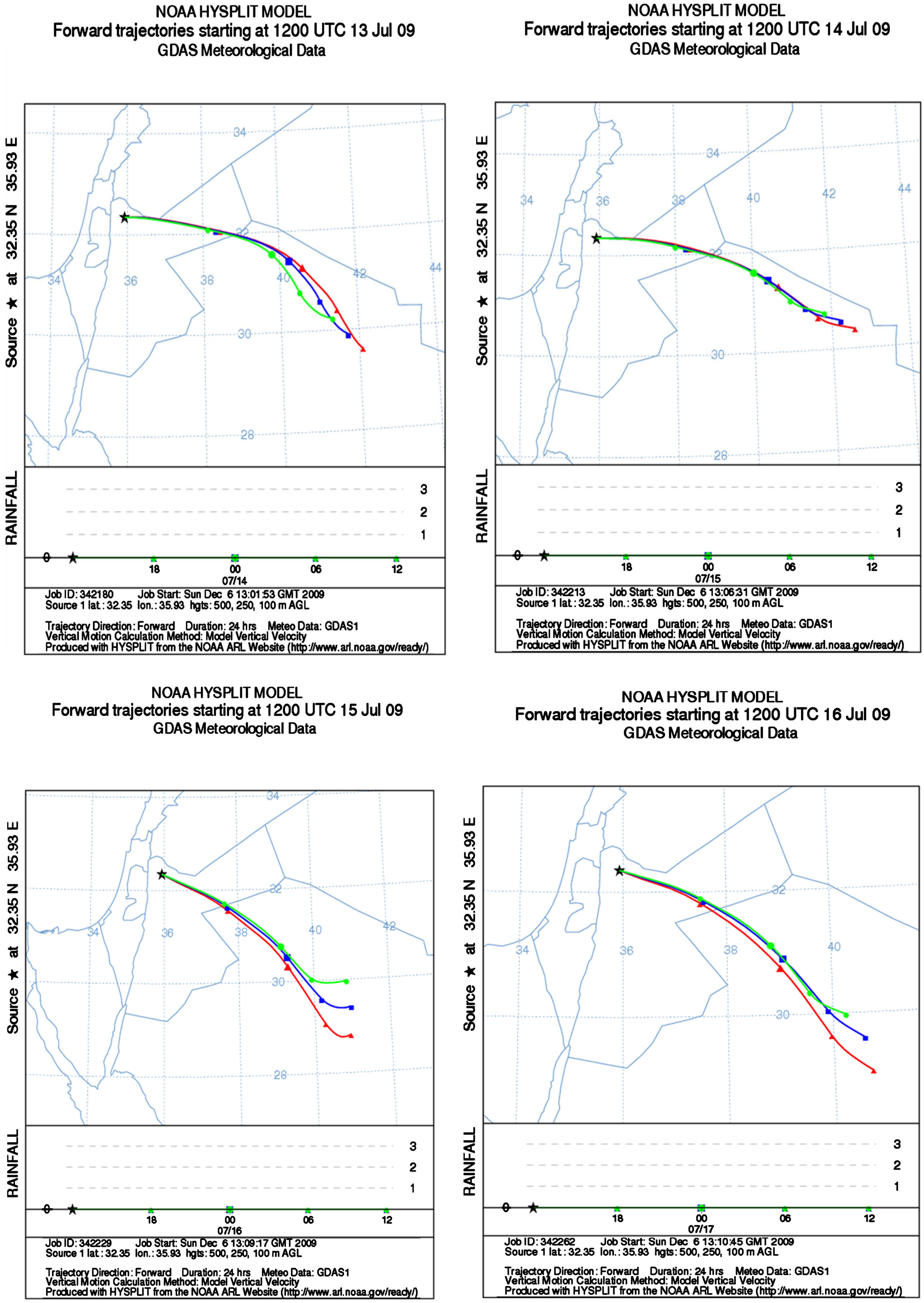


Figure 10. Wind direction and speed distribution for the study area during the period (January 2009 to November 2009).




NOAA HYSPLIT MODEL
Forward trajectories starting at 1200 UTC 13 Jul 09
GDAS Meteorological Data
Source ★ at 32.35 N 35.93 E
RAINFALL
Job ID: 342180 Job Start: Sun Dec 6 13:01:53 GMT 2009
Source 1 lat.: 32.35 lon.: 35.93 hgts: 500, 250, 100 m AGL
Trajectory Direction: Forward Duration: 24 hrs Meteo Data: GDAS1
Vertical Motion Calculation Method: Model Vertical Velocity
Produced with HYSPLIT from the NOAA ARL Website (http://www.arl.noaa.gov/ready/)
NOAA HYSPLIT MODEL
Forward trajectories starting at 1200 UTC 14 Jul 09
GDAS Meteorological Data
Source ★ at 32.35 N 35.93 E
RAINFALL
Job ID: 342213 Job Start: Sun Dec 6 13:06:31 GMT 2009
Source 1 lat.: 32.35 lon.: 35.93 hgts: 500, 250, 100 m AGL
Trajectory Direction: Forward Duration: 24 hrs Meteo Data: GDAS1
Vertical Motion Calculation Method: Model Vertical Velocity
Produced with HYSPLIT from the NOAA ARL Website (http://www.arl.noaa.gov/ready/)
NOAA HYSPLIT MODEL
Forward trajectories starting at 1200 UTC 15 Jul 09
GDAS Meteorological Data
Source ★ at 32.35 N 35.93 E
RAINFALL
Job ID: 342229 Job Start: Sun Dec 6 13:09:17 GMT 2009
Source 1 lat.: 32.35 lon.: 35.93 hgts: 500, 250, 100 m AGL
Trajectory Direction: Forward Duration: 24 hrs Meteo Data: GDAS1
Vertical Motion Calculation Method: Model Vertical Velocity
Produced with HYSPLIT from the NOAA ARL Website (http://www.arl.noaa.gov/ready/)
NOAA HYSPLIT MODEL
Forward trajectories starting at 1200 UTC 16 Jul 09
GDAS Meteorological Data
Source ★ at 32.35 N 35.93 E
RAINFALL
Job ID: 342262 Job Start: Sun Dec 6 13:10:45 GMT 2009
Source 1 lat.: 32.35 lon.: 35.93 hgts: 500, 250, 100 m AGL
Trajectory Direction: Forward Duration: 24 hrs Meteo Data: GDAS1
Vertical Motion Calculation Method: Model Vertical Velocity
Produced with HYSPLIT from the NOAA ARL Website (http://www.arl.noaa.gov/ready/)

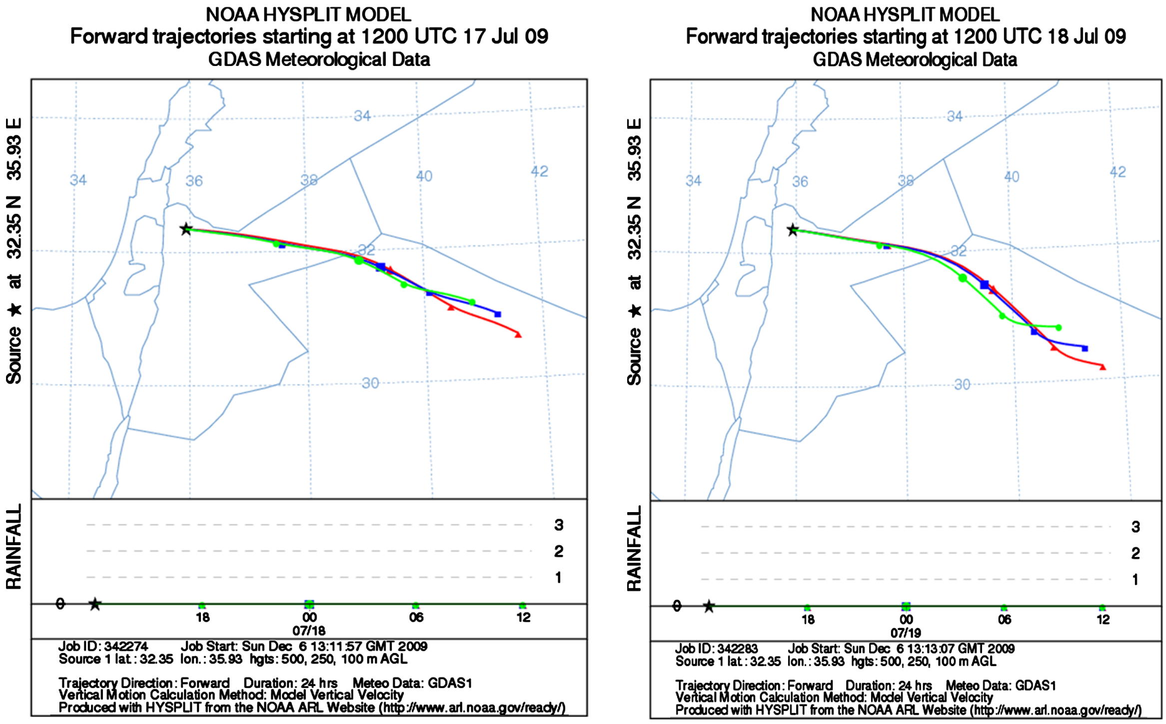


Figure 11. Trajectory plots of the maximum wind speed.

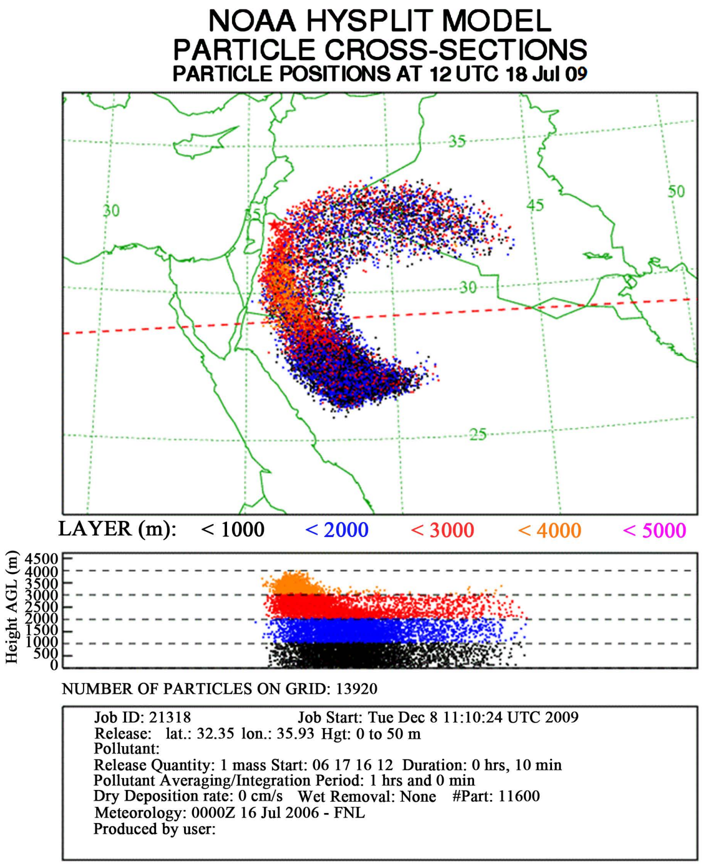


Figure 12. Trajectory plots of the particle positions at the day 18 Jul. 2009 (summer season).

3.2.3. Trends Analysis for Wind Speed and Concentrations

Based on the trend analysis for the wind speed and concentration it can be noticed that there are relationships between wind velocity (average and maximum) and air quality levels. To establish this relationship, **Figures 13-18** and **Table 3** show the time series for these variables. Due to the difficulties for the measurements of wind speed during the day and night, so in this study the average of weekly wind speed has been used for both areas. The results are shown in **Table 3**. It can be noticed that the minimum wind speed was measured from the period 7-20 February and reached up to 6 - 9 m/s, while the maximum wind speed was measured from 11 - 17 July and reached up to 10 - 20 m/s.

1) First area station (Shatana)

2) Second area station (Rahma)

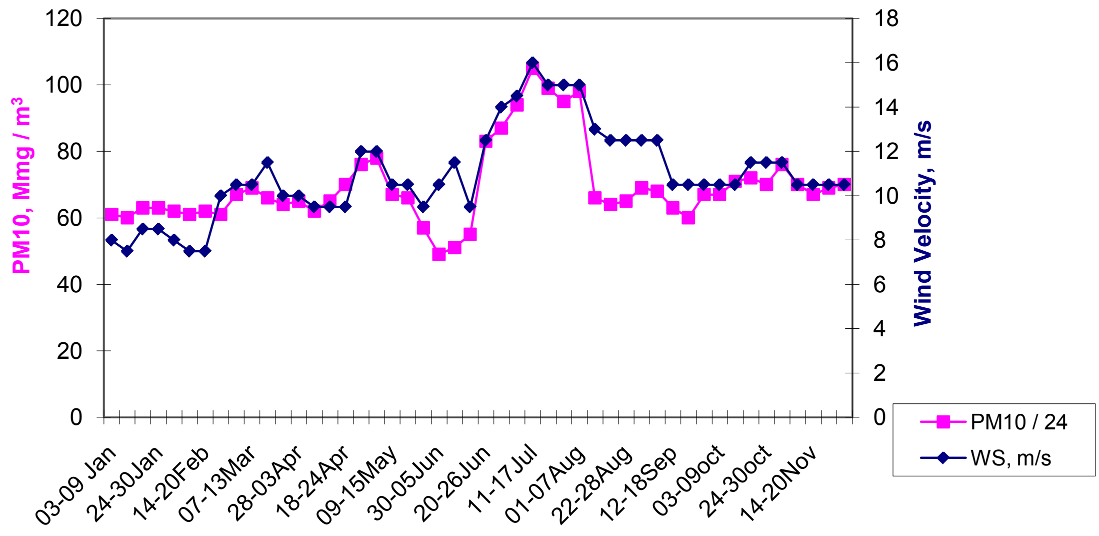


Figure 13. Trend relation between the measured concentrations of PM10 and wind speed at first station area (Shatana) for 24 hours.

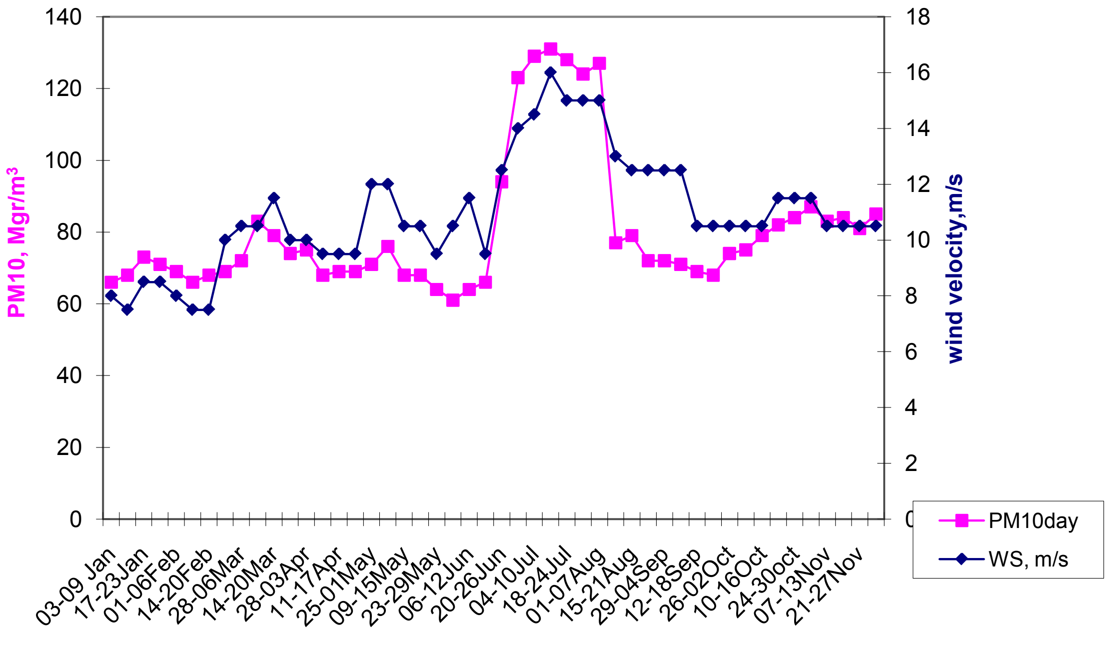


Figure 14. Trend relation between the measured concentrations of PM10 and wind speed at first station area (Shatana) for day work.

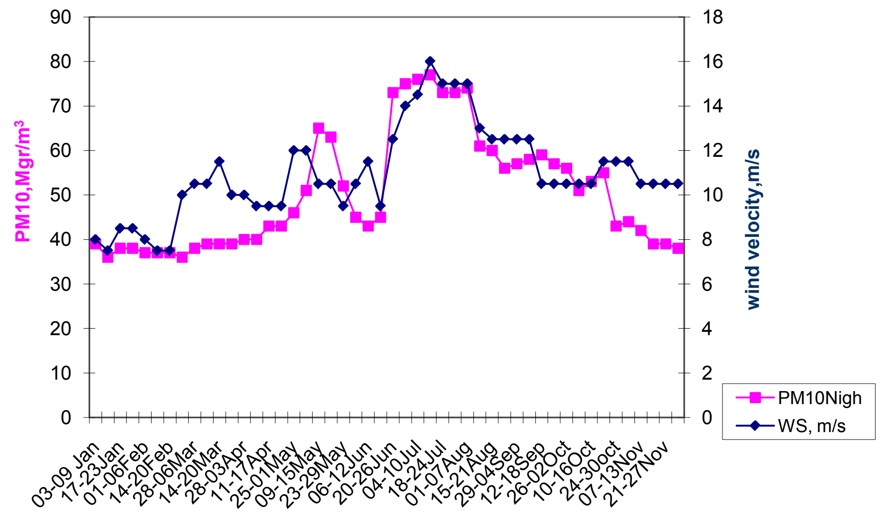


Figure 15. Trend relation between the measured concentrations of PM10 and wind speed at first station area (Shatana) at night.

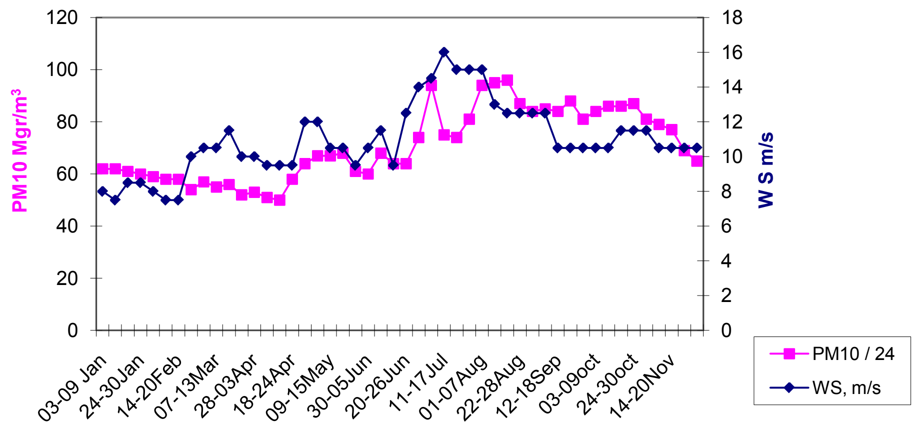


Figure 16. Trend relation between the measured concentrations of PM10 and wind speed at second station area (Rahma) for 24 hours.

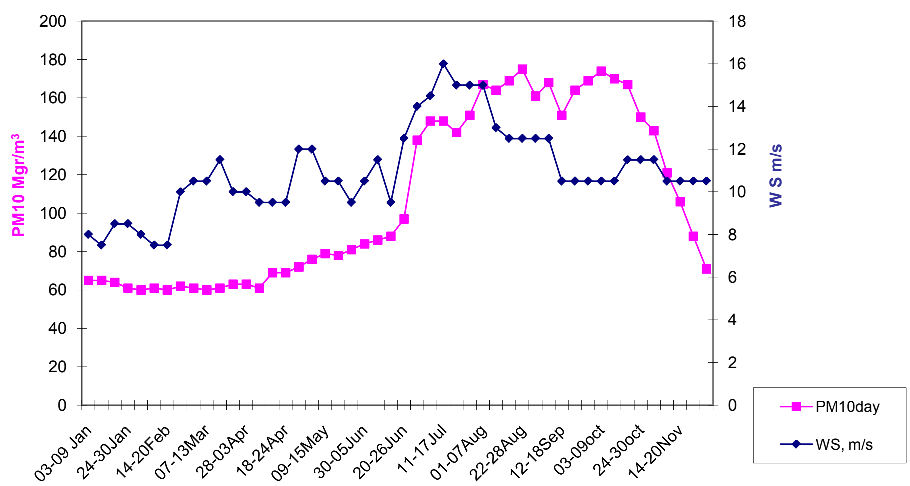


Figure 17. Trend relation between the measured concentrations of PM10 and wind speed at second station area (Rahma) for day work.

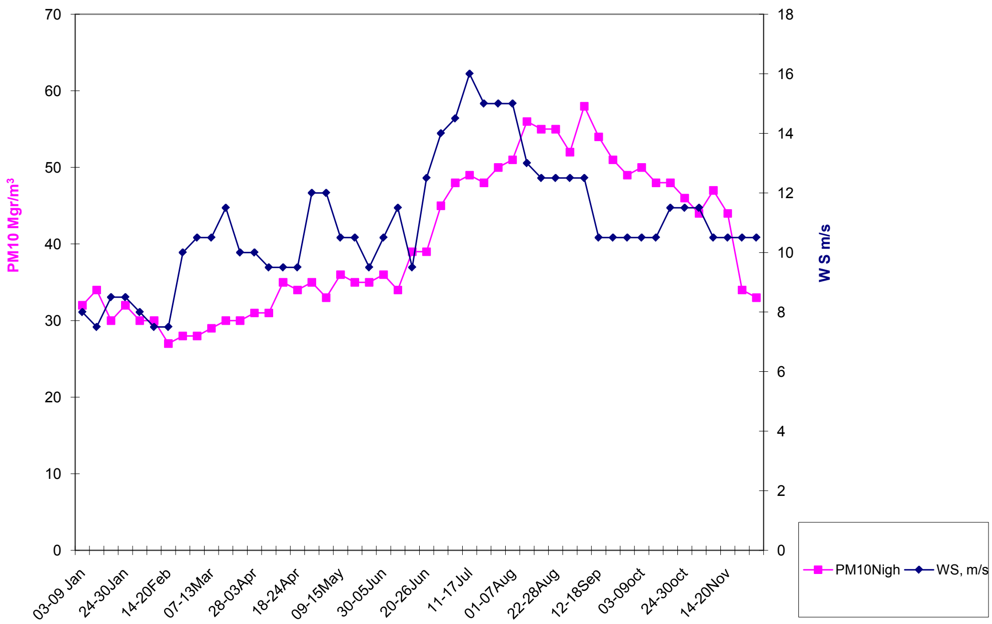


Figure 18. Trend relation between the measured concentrations of PM10 and wind speed at second station area (Rahma) at night.

Table 3. Average of weekly wind speed for both areas (Shatana and Rahma).

Date	Wind speed	Date	Wind speed
03-09 Jan.	7 - 8 m/s	04-10 Jul.	10 - 19 m/s
10-16 Jan.	7 - 8 m/s	11-17 Jul.	10 - 22 m/s
17-23 Jan.	8 - 9 m/s	18-24 Jul.	10 - 20 m/s
24-30Jan.	7 - 10 m/s	25-31 Jul.	10 - 20 m/s
01-06 Feb.	7 - 9 m/s	01-07 Aug.	10 - 20 m/s
07-13 Feb.	6 - 9 m/s	08-14 Aug.	9 - 17 m/s
14-20 Feb.	6 - 9 m/s	15-21 Aug.	9 - 16 m/s
21-27 Feb.	8 - 13 m/s	22-28 Aug.	9 - 16 m/s
28-06 Mar.	7 - 14 m/s	29-04 Sep.	9 - 16 m/s
07-13 Mar.	8 - 15 m/s	05-11 Sep.	9 - 16 m/s
14-20 Mar.	8 - 13 m/s	12-18 Sep.	7 - 14 m/s
21-27 Mar.	8 - 12 m/s	19-25 Sep.	7 - 14 m/s
28-03 Apr.	8 - 12 m/s	26-02 Oct.	7 - 14 m/s
04-10 Apr.	8 - 11 m/s	03-09 Oct.	7 - 14 m/s
11-17 Apr.	8 - 11 m/s	10-16 Oct.	7 - 14 m/s
18-24 Apr.	8 - 11 m/s	17-23 Oct.	7 - 16 m/s
25-01 May	9 - 15 m/s	24-30 Oct.	7 - 16 m/s
02-08 May	9 - 15 m/s	31-06 Nov.	7 - 16 m/s
09-15 May	8 - 13 m/s	07-13 Nov.	7 - 14 m/s
16-22 May	8 - 13 m/s	14-20 Nov.	7 - 14 m/s
23-29 May	7 - 12 m/s	21-27 Nov.	7 - 14 m/s
30-05 Jun.	6 - 15 m/s	28N-04 Dec.	7 - 14 m/s
06-12 Jun.	7 - 16 m/s	5-11 Dec.	7 - 15 m/s
13-19 Jun.	7 - 13 m/s	12-18 Dec.	7 - 14 m/s
20-26 Jun.	9 - 16 m/s	19-25 Dec.	8 - 16 m/s
27-03 Jul.	10 - 18 m/s	26-1 Jan.	8 - 15 m/s

3.2.4. Trends Analysis for Rainfall and Air Quality

Open mine operations mainly have a fugitive dust sources, the emissions depend on the humidity and the control of the minig activities. The rain is a natural control mechanism, especially for coarse material, and many studies show that this "natural control" must be included in the emission factor calculations and in the washout removal mechanism into the atmosphere. **Figure 19** shows the trends and relationships between the rainfall and the concentration average. In **Table 4** and **Table 5** are shown the average of monthly rainfall and the concentration of PM10 at Shatana and Rahma areas. It can be noticed from the obtained data as shown in the tables that when the rainfall is increased durnig winter season the average of PM10 decreases, while when the rainfall decreased in the summer season the average of PM10 increases. However, it can be noticed that the amount of the rainfall in both area are relatively similar but the wind speed is a little bit different.

3.2.5. Correlation Analysis for Average Wind Speed and Concentrations

Figure 20 shows the $\mathbf{R^2}$ correlation factor for the wind speed and concentrations. It can be assumed that the trend is very clear in Shatana station ($R^2 = 0.639$), while in Rahma station is relatively less than Shatana station ($R^2 = 0.409$).

4. Sources of Emissions

EPA-AP42 document have been used to calculate the emissions factor. The factors are used for each activity [15]. The source and name of the emission factor with its reference is shown in **Table 6**.

5. Conclusions and Recommendations

The results of analysis are revealed to the major conclusions. By comparing the measured concentrations of PM10 with the Jordanian standard at first station area (Shatana), it can be noticed that during the winter season the concentration of PM10 is equal to or below the Jordanian standard, while during summer season the concentration of PM10 is over the Jordanian standard with recording the data of 24 hours. With recording the data at day work (from 6 a.m. to 6 p.m.), from 7 March to 3 April, the concentration of PM10 was over the Jordanian standard (with about 10 µg/m³). In summer season, the concentration of PM10 was over the Jordanian standard

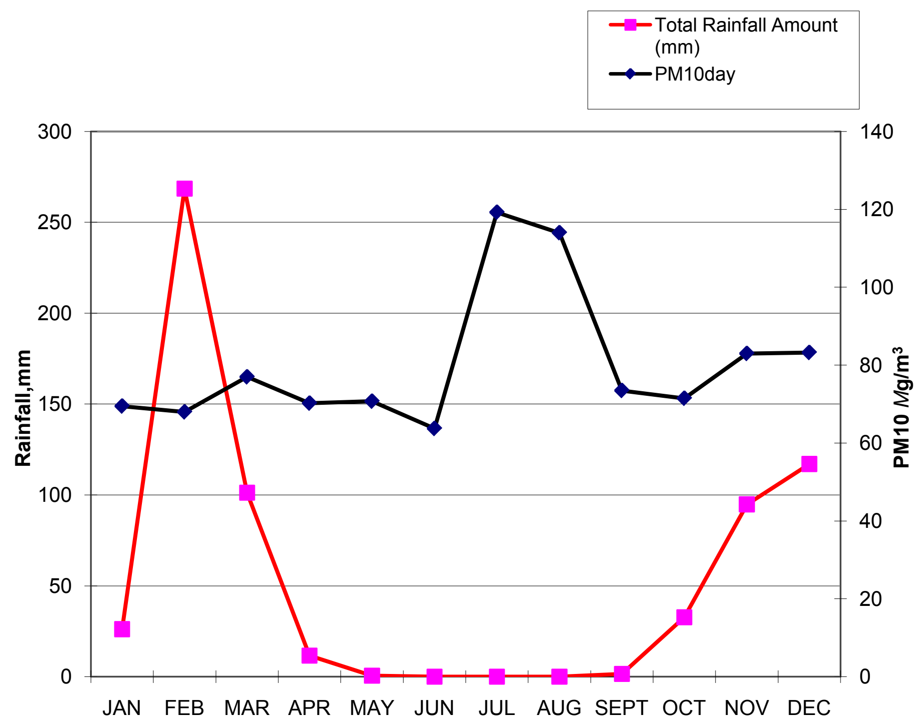
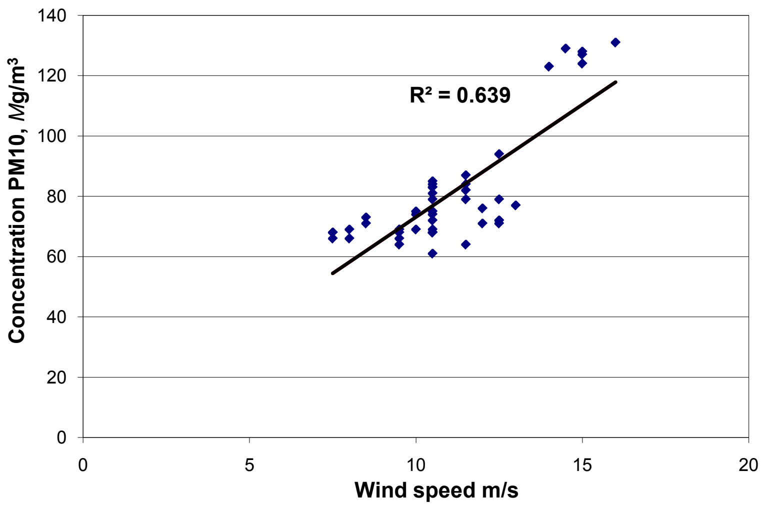
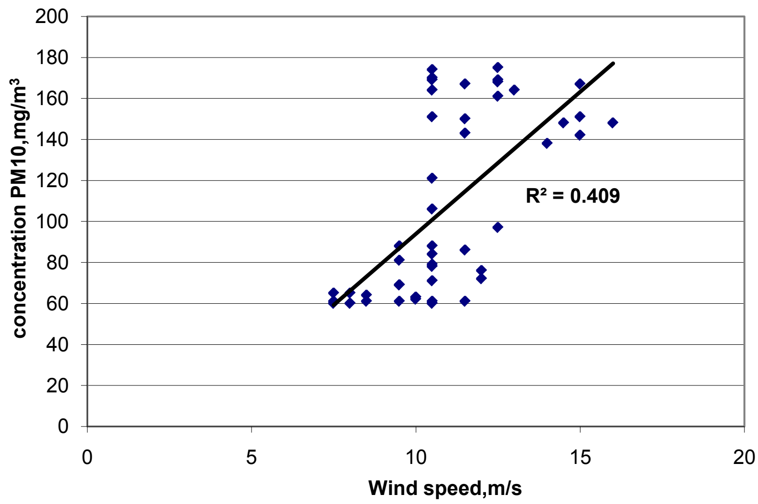


Figure 19. Trend and relation between rainfall and average concentrations of PM10.



(a)



(b)

Figure 20. Correlation of concentration of PM10 at Shatana area (a) and Rahma area (b).

Table 4. Average monthly rainfall and concentration of PM10 at Shatana area.

Month	Total rainfall amount (mm)	Avg. PM10/day time
Jan.	260.1	69.5
Feb.	268.5	50.3
Mar.	101.2	70
Apr.	11.6	71.25
May	0.5	73.75
Jun.	0	75.25
Jul.	0	119.25
Aug.	0	114
Sept.	1.5	73.5
Oct.	32.7	75
Nov.	94.8	83
Dec.	117	85.25

Table 5. Average monthly rainfall and concentration of PM10 at Rahma area.

Month	Total rainfall amount (mm)	Avg. PM10/day time
Jan.	260.1	63.75
Feb.	268.5	60.75
Mar.	101.2	61.25
Apr.	11.6	65.5
May	0.5	77.2
Jun.	0	88.75
Jul.	0	145.4
Aug.	0	168.75
Sept.	1.5	161
Oct.	32.7	166
Nov.	94.8	114.5
Dec.	117	96

Table 6. The source and name of the emission factor with its reference.

Source		**Name of emission factor**	**Reference**
Source: PIT			
PIT1	Drilling	Drilling	AP-42 Table 11.9 - 4
PIT2	Blasting	Blasting	AP-42 Table 11.9 - 2
PIT3	Sterile Loading	Storage piles	AP-42 Section 13.2.4.
PIT4	Load of conveyor system	Bulldozing	AP-42 Table 11.9 - 2
PIT5	Transit of waste trucks	Unpaved roads	AP-42 Section 13.2.2.
PIT6	Waste operations of auxiliary equipment	Bulldozing	AP-42 Table 11.9 - 2
PIT7	Limestone loading	Truck loading	AP-42 Table 11.9 - 2
PIT8	Transit of limestone trucks	Unpaved roads	AP-42 Section 13.2.2.
PIT9	Transit of light duty vehicles	Unpaved roads	AP-42 Section 13.2.2.
Source: waste areas			
BOT1	Sterile truck unloading	Storage piles	AP-42 Section 13.2.4.
BOT2	Sterile conveyor unloading	Storage piles	AP-42 Section 13.2.4.
BOT3	Bulldozing of waste areas	Bulldozing	AP-42 Table 11.9 - 2
BOT4	Wind erosion of exposed areas	Wind erosion of exposed areas	AP-42 Table 11.9-2
BOT5	Transit of sterile trucks on the waste area	Unpaved roads	AP-42 Section 13.2.2.
SOURCE: LIMESTONE YARD			
PAT1	Limestone truck unloading	Storage piles	AP-42 Section 13.2.4.
PAT2	Limestone unloading to conveyor	Storage piles	AP-42 Section 13.2.4.
PAT3	Bulldozing of limestone	Bulldozing	AP-42 Table 11.9 - 2
PAT4	Train and truck loading	Storage piles	AP-42 Section 13.2.4.
PAT5	Wind erosion of limestone yard	Active storage piles	AP-42 Table 11.9 - 2
PAT6	Transit of limestone trucks on the limestone yard	Unpaved roads	AP-42 Section 13.2.2.
Source: roads			
VIA1	Transit road pit-waste area	Unpaved roads	AP-42 Section 13.2.2.
VIA2	Transit limestone road Pit Limestone Yard	Unpaved roads	AP-42 Section 13.2.2.
VIA3	Light duty transit on surrounding roads	Unpaved roads	AP-42 Section 13.2.2.

(with more than 50 μg/m^3). From October to December, the concentration of PM10 rises with small amount over the Jordanian standard. In other seasons, the concentration of PM10 is equal to or below the Jordanian standard. With recording the data at night as shown in the graphics, the concentration of PM10 was over the Jordanian standard only in summer time (June-July).

By comparing the measured concentrations of PM10 with the Jordanian standard at second station area (Rahma), it can be noticed that during the winter season the concentration of PM10 is equal to or below the Jordanian standard (January to May, and December), with recording the data of 24 hours, while during summer season the concentration of PM10 is over the Jordanian standard from May to November.

With recording the data at day work (from 6 a.m. to 6 p.m.) during summer season, the concentration of PM10 is over the Jordanian standard (from April to November). During winter season, the concentration of PM10 is below the Jordanian standard (from December to April). From November, the concentration of PM10 starting decreases. With recording the data at night, as shown in the graphic, the concentration of PM10 is below the Jordanian standard during the year.

Comparing the measured concentration of PM10 in both areas with the Jordanian standard, it can be concluded that the concentration of PM10 increases in summer season during day work. The range of PM10 value was 120 - 140 μg/m^3, and the value of PM10 during other seasons was around the Jordanian standard (70 μg/m^3).

Analysis of trend relation between the measured concentration of PM10 and wind speed at both station areas (Shatana and Rahma) for 24 hours during 24 hours, day work and at night, as shown in **Figures 13-18**, indicates the trend relationships between the measured concentrations of PM10 and the wind speed for different periods of time. It can be noticed that when the wind speed increases, the concentrations of PM10 decrease in winter season, while in summer season when the wind speed increases the concentrations of PM10 increase.

From the analysis trend and relation between rainfall and the concentration of PM10, it can be concluded that the measured concentration during winter season is below or around the Jordanian standard (70 μg/m^3), while in the summer (Jul. and Aug.) the concentration increases (as shown in **Figure 19**). It can be noticed from the obtained data as shown in **Table 4** and **Table 5** that when the rainfall is increased during winter seasons the average of PM10 decreases, while when the rainfall decreases in the summer season the average of PM10 increases.

Forward trajectories have shown that pollutants attributed to the mining activities inside the quarries, and distributed outside the mining areas depend on the wind speed and wind direction. Comparing the measured concentration of PM10 with rainfall, it can be assumed that the concentration of PM10 decreases in winter season during day work. **Figure 20** shows the R^2 correlation factor for the wind speed and concentrations. The correlation factor at Shatana station is around 0.6395, while the correlation factor at Rahma station is around 0.4095. It can be assumed that the trend is very clear and more affective in Shatana station, while in Rahma station the trend is relatively less affective.

It can be concluded that the dust has effects on the health and safety of workers in mines and residents living in the urban areas near the quarries, as well as on the biodiversity in the region. Monitoring and follow-up measurements of dust levels in the atmosphere are important elements to preserve the environment in these areas. The authorities in Jordan are developing air quality plans to bring PM10 and PM2.5 concentrations down to healthful levels. These plans include a variety of regulations and programs to reduce emissions, including dust control for transport, mines and quarries. However, there are some procedures that can lead to reduce the threat of PM10 such as: 1) scheduling the activities of mining, loading, transport and dumping to coincide with favourable atmospheric conditions; 2) to avoid blasting under unfavourable wind and atmospheric conditions; 3) wet drilling will minimize and mitigate the dust emissions; 4) application of water during topsoil stripping may be affective, and many of mining activities can be scheduled during the period when the soil has the optimal moisture; 5) minimizing of exposed areas through careful planning; 6) rehabilitation and revegetation are continuous work and will help in mitigation of pollution; 7) to limit the speed of vehicles on haul roads and to drive with limited speed on unpaved roads, and to spray water during mining activities and during transportation; 8) to be involved with air quality improvement programs in the urban areas near to Sammad and other similar areas around and to work with local agencies to develop strategies that will further reduce the PM10 emissions and to save the biodiversity in the studied area.

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Authors' Contributions

All authors conceived of the research and wrote the paper. They analyzed the data, discussed and commented the results and implications.

Conflicts of Interests

The authors declare no conflict of interest.

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