Impact Assessment of Ambient Air Quality by Cement Industry: A Case Study in Jordan

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ABSTRACT

Cement industry is flourishing in the Middle East and North African countries due to the rapid population growth, the change in living style, and the availability of raw material in the region. Unless restricted regulations are enforced by local authorities to ensure compliance with national and international standards upon this industry, the increase of cement factories and their associated quarries in the region may deteriorate air quality and thus threaten the fragile ecosystems in the region. This paper presents predictions of air pollution (dust, SO_2, NO_x and CO) emitted from a modern cement plant that will be constructed in the Jordan Badia South-East of Amman. AERMOD is used to carry out the modeling part of this assessment. Our findings indicate that after the implementation of the proposed project, concentrations of air pollutant are found to be well below the permissible Jordanian Standards for ambient air quality. Therefore, the proposed activity is not likely to have any significant adverse impact on the air environment in the vicinity of the proposed project. However, The TSP concentration is expected to be high at the limestone quarry, which provides the factory with its main raw material, because it generates lots of dust as a result of rocks mining and crushing.

Keywords: Atmosphere; Cement; Emission; Environment; Modeling; Pollution; Impact assessment.

INTRODUCTION

Air pollution continues to receive a great deal of interest worldwide due to its negative impacts on human health and welfare. Several studies reported significant correlations between air pollution and certain diseases including shortness of breath, sore throat, chest pain, nausea, asthma, bronchitis and lung cancer (Dockery and Pope, 1994; U.S. EPA 1999a; U.S. EPA 1999b; Jeff and Hans 2004; Clean Air 2007). Extreme effects of air pollution include high blood pressure and Cardiovascular problems (Pope, 2002; Sanjay, 2008). Correlations between air pollution and increased morbidity and mortality rates were reported (Pope 1995; Laden *et al.*, 2000). The World Health Organization states that 2.4 million people die each year from causes directly attributable to air pollution (WHO, 2007). Epidemiological studies suggest that more than 500,000 Americans die each year from cardiopulmonary disease linked to breathing fine particle air pollution (American Chemical Society, 2008). Another study has shown a strong correlation between pneumonia related deaths and air pollution from motor vehicles in UK (Knox, 2008). In addition to its negative health impacts, air pollution is known to cause injuries to animals, forests and vegetation, and aquatic ecosystems. Its impacts on metals, structures, leather, rubber, and fabrics include cracks, soiling, deterioration, and erosion (Boubel *et al.*, 1994).

Cement industry is a potential anthropogenic source of air pollution. It is a major contributor to dust, nitrogen oxides (NO_x), sulfur oxides (SO_x), and carbon monoxide (CO) in metropolitan areas. Furthermore, it contributes about 5% of the global CO_2, the famous green house gas (Ian and David, 2002). In cement industries, dust is emitted from stock piles, quarrying, transportation of raw materials, kilns operation, clinker cooling and milling (EIPPC2001). Oxides of carbon, nitrogen, and sulfur are mainly produced as a byproduct of fuel combustion for power generation (Marland *et al.*, 1989; Ruth, 2000; Battelle Institute, 2002; Ian and David, 2002). In addition; SO_2 is produced from oxidation of volatile sulfur present in the kind of limestone used as raw material (Jeff and Hans, 2004).

Cement consumption rates increased during the last ten years (2001–2010) in most Arab countries, particularly in the Gulf Corporation Countries. Export rates also increased, particularly from Egypt, Jordan and Lebanon to Arab and international close and distant countries. Available information indicate that the Arab cement industry has witnessed capacity additions in the recent years with the total installed capacity touching 222 million tons per year from the168 cement factories in the Arab region. The rush

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of a large number of investors towards constructing new cement plants or expanding current capacities of some existing plants will more than double these capacities. These expansions attributed to the substantial increase of consumption rates in most Arab countries, the issuance of investment encouragement laws and regulations by Arab countries, and the availability of cement raw material in abundant quantities in the region.

In Jordan, new cement plants are being constructed in Badia (a region that receives less than 150 mm of rain annually). However, only few studies were conducted to assess the air quality in the country. The Royal Scientific Association have monitored PM_{10} and $PM_{2.5}$ in Alhashemeiah, a town where most of Jordan industries are concentrated during the interval March, 2000 through February 2001 (Asi *et al*., 2001). The results showed that PM_{10} and $PM_{2.5}$ have exceeded the Jordanian 24 hour standard of 120 µg/m^3 during 20 days out of 50 days constitute the whole sampling period. Hussein *et al*. (2010) measured the submicron particle number concentrations in the urban/suburban atmosphere of Amman–Jordan during the spring of 2009 and found that during the morning rush hours the number concentrations were as high as 120×10^3 and 75×10^3 1/cm^3 at the urban and suburban sites during weekly workdays.

Special attention has to be paid to any proposed activities in arid regions in order to minimize the environmental consequences of dust accumulated on shrubs and herbs, which may lead to their death, and thereby destroy the fragile ecosystem therein. Therefore, the objectives of this study are: to address air quality impact of cement industry in the Middle East and North Africa, to identify the possible impact of a proposed cement factory in Jordan Badia Located 120 km South-East of Amman; and to recommend appropriate mitigating measures, which could assist the company to comply with the Jordanian standards for ambient air quality.

ENVIRONMENTAL SETTING

Climatology

Jordan Badia has a climate characterized by extreme heat during the day, rapid cooling at night, and slight, irregular rainfall, with the exception of occasional cloudbursts that can cause flash flooding when they occur. Temperatures may rise above 40°C during the summer season.

Weather patterns in Jordan are strongly influenced by phenomena originating in central Asia during winter, and in India and Iran during the summer (Reynolds, 1993). During winter, large scale meteorological features which influence Jordan are southward extending ridges of high pressure from central Asia, interrupted by depressions moving eastward from the Mediterranean Sea (Perrone, 1979; Murthy and El-Sabh, 1983; Reynolds, 1993). Associated cold fronts can cause squalls, rain and thunderstorms. The depressions are usually preceded by southwest winds and followed by northwest winds that cause sand and dust storms during Autumn and Spring. Summer lasts from May through September with the hottest months being July and August. In the summer a large thermal low forms over North-

Western India and Iran. Jordan Badia is on the western part of this semi-permanent low, resulting in prevailing North-Westerly winds throughout the summer.

Alqutraneh is the closest meteorological station to the project site, therefore its data for the years 1986–2009 (Table 1) are used in this study to describe the climate of the project area (Al Smadi *et al*., 2009). Information obtained from that station indicates that the project is located in a semi-arid climate described by hot-dry summer and wet-mild winter with less than 150 mm total annual rainfall. The average annual temperature is 17.1°C, with minimum temperature of 2.4°C recorded during the month of January and maximum temperature of 32.6°C recorded during the month of August. Average relative humidity ranges between 39.3% during the month of May and 70.3% during the month of January. The minimum evaporation is 1.9 mm per day reached during the month of December, while the maximum evaporation is 10.1 mm per day reached during the month of July. Solar radiation is fairly well in the project site where it peaks during June and July. A total of 686 hours of solar radiation is received during these two months only. Wind direction fluctuates between North-West to South-West during autumn and winter, whereas westerly wind dominate summer days. The highest wind speed is 3.1 m/s measured during March. The wind plays important role in kicking of soil particles and generating fugitive dust especially in a dry region where the cement project is proposed.

Air Quality

Environmental baseline describing preconstruction air quality was obtained through intensive measurements of criteria air pollutants. Total suspended particles (TSP), particulate matter with aerodynamic diameter less than or equal to 10 micrometer (PM_{10}), particulate matter with aerodynamic diameter less than or equal to 2.5 micrometer ($PM_{2.5}$), lead, carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide, and hydrogen sulfide, were measured at the proposed project site for four consecutive days. Measurement results are presented in Table 2. Gaseous pollutants and lead were all below detection limits during measurement period. However particulate matter "particularly TSP" were relatively high because measurements took place during the Khamaseen episode, were south-westerly wind that origins in the South of Libya and Egypt prevails. Windy and dusty weather conditions are usually associated with Khamaseen. Dust concentration was excessively high during the last sampling day (Tuesday), therefore it was treated as an out layer and excluded from the daily average.

AIR QUALITY IMPACT OF THE PROJECT

Impact during Construction Phase

During construction phase, dust will be the main pollutant, which would be generated from the site development activities and vehicular movement on the road. The impact of such activities would be confined within the project boundary and restricted to the construction phase. To mitigate these impacts, regular sprinkling of water will be

Table 1. Data for a long period as obtained from Alquatraneh Meteorological Station (Al Smadi *et al.*, 2009).

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Mean Max Temperature (°C)	13.7	14.8	17.9	24.2	28.7	31.0	32.4	32.6	31.0	26.9	20.9	15.7	24.2
Mean Min Temperature (°C)	2.4	2.7	5.2	9.2	12.9	15.2	17.3	17.1	15.0	11.6	7.1	3.4	9.9
Temperature Mean (°C)	8.0	8.8	11.6	16.7	20.8	23.1	24.9	24.9	23.1	19.3	14.0	9.5	17.1
Absolute Max Temperature (°C)	25.0	28.0	30.8	36.5	38.4	41.0	43.0	43.2	40.0	36.0	32.0	28.1	43.2
Absolute Min Temperature (°C)	–4.0	–6.0	–2.8	–2.0	3.4	8.0	11.0	12.0	8.4	4.0	–4.0	–5.0	–6.0
Mean Relative Humidity %	70.3	65.9	59.7	43.5	39.3	41.6	44.4	48.9	51.5	53.5	57.9	68.0	53.7
Solar Radiation	288	353	450	555	615	686	673	642	559	449	339	273	490
Wind Direction	SW-NE	SW-NE	SW-NE	NW-SE	SW-NE	NW-SE	NW-SE	NW-SE	NW-SE	NW-SE	SW-NE	SW-NE	SW-NE
Mean Wind Speed (Knot)	5.2	5.7	6.2	5.3	5.2	5.9	6.0	4.5	3.6	3.2	4.7	5.1	5.1
Mean Total Rainfall (mm)	25.9	22.5	20.9	6.4	3.1	0.0	0.0	0.0	0.0	4.1	8.4	19.6	110.9
No. Rainy days ≥ 0.1 mm	6.4	6.3	5.6	1.4	0.7	0.1	0.0	0.0	0.1	1.9	3.1	5.4	31.0
Total Evaporation (mm)	68.0	89.7	133.6	210.5	291.1	399.0	327.3	297.4	228.6	163.0	114.6	73.4	192.3
Mean Daily Evaporation (mm)	2.0	2.9	3.4	7.3	9.2	9.8	10.1	8.8	7.3	5.1	2.6	1.9	5.9

done at the construction site. Approaching roads will be black carpeted and vehicles will be kept in good order to minimize automobile exhaust.

Impact during Operational Phase

The operational phase is the most important stage in terms of its impact on air quality, as characterized by emission of massive quantities of fugitive dust and oxides. Air pollutants generated during the cement manufacturing process consist primarily of particulates from the raw and finished materials, and fuel combustion by-products. Particulate matter are emitted through the following stages:

1. Procurement of raw materials
2. Raw Milling - preparation of raw materials for the pyroprocessing system
3. Pyroprocessing - pyroprocessing raw materials to form portland cement clinker
4. Cooling of portland cement clinker
5. Storage of portland cement clinker
6. Finish Milling
7. Packing and loading

Controlling particulate emissions from sources other than the kiln usually entails capturing the dust using a hood or other partial enclosure and transporting it through a series of ducts to the collectors. The type of dust collector used is based on factors such as particle size, dust loading, flow rate, moisture content, and gas temperature. The best disposal method for collected dust is to send it through the kiln creating the clinker. However, if the alkali content of the raw materials is too high, the dust must be discarded, or must be pre treated before introduction into the kiln. The highest allowable alkali content is 0.6 percent (as sodium oxide).

Additional air pollutants emitted include sulfur oxides and nitrogen oxides generated from the kiln and drying processes. Sulfur dioxide is generated from the sulfur compounds in the combusted fuel. The combustion of fuel in rotary cement kilns generates nitrogen oxides from the nitrogen in the fuel and incoming combustion. Both sulfur dioxide and some of the nitrogen oxide react with the alkaline cement and are removed from the gas stream.

RESULTS AND DISCUSSION

Prediction of impacts on air quality has been carried out by using AERMOD Regulatory Model which is based on the famous Gaussian Plume Dispersion. AERMOD is developed by The U.S. Environmental Protection Agency (EPA), in conjunction with the American Meteorological Society (AMS) (EPA-454/R-03-004).

AERMOD Input

Specifications of stacks used in different units in the plant are summarized in Table 3, and emission rates from all project units are summarized in Table 4. Emission rates of gaseous pollutants were obtained from Jordanian Standards for Stationary Sources (JS-1189/2006), while those for dust were obtained from published literature, including the emission inventory of the U.S. Environmental Protection Agency (EPA: AP-42).

Table 2. Concentration of airborne particulate matter and lead at project site during the period 8–11/5/2010.

Day	Date	TSP ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	Lead ($\mu g/m^3$)
Saturday	11/5/2010	104.2	53.9	20.9	Not detected
Sunday	11/5/2010	127.5	61.3	28.3	Not detected
Monday	11/5/2010	196.7	80.3	45.2	Not detected
Tuesday	11/5/2010	243.3	106.2	56.6	Not detected
Daily Average		142.8	65.2	31.4	Not detected
Annual Average[1]		6.3	2.9	1.4	

[1] Calculated from the formula $C_{Annual} = C_{Daily} \times (1/365)^{0.53}$

Table 3. Specifications of Stacks used in different units in the cement plant, burning and grinding.

Stack Gas Temperature (°K)	Stack Diameter	Stack Height	Unit
400° K	3.0 m	90 m	Kiln
470°K	3.2 m	32 m	Clinker Cooler
380°K	1.5 m	42 m	Cement Mill

Table 4. Emission rates of dust and gases emitted from all components of the project.

Pollutant	Unit	Emission Rate
TSP	Quarry	1×10^{-5} g/(s.m²)[1]
	Kiln	10.2 g/s
	Clinker Cooler	8.5 g/s
	Cement mill	1.6 g/s
	Volume	2.1 g/s
PM_{10}	Quarry	5×10^{-6} g/(s.m²)
	Kiln	5.1 g/s
	Clinker Cooler	4.2 g/s
	Cement mill	0.8 g/s
	Volume	1.0 g/s
$PM_{2.5}$	Kiln	2.5 g/s
	Clinker Cooler	2.1 g/s
	Cement mill	0.4 g/s
CO	Kiln	21.5 g/s[2]
NO_x	Clinker cooler	154. 9g/s[2]
SO_2	Cement mill	560 g/s[2]

[1] Calculated based on emission rates from quarries and massive drilling and construction sites, which is 2.69 ton/ha.year.

[2] According to Jordanian standards for emissions from stationary sources (JS 1189/2006).

Two meteorological files for input to AERMOD are required; Surface Observations and Upper Air Sounding. Surface observation data include wind speed and direction, ambient air temperature, total sky cover, and station pressure. Upper air sounding data include atmospheric pressure at upper altitudes, height above ground level, dry bulb temperature, wind direction, wind speed.

Records from Alqutraneh, the closest meteorological station to the project site, do not have upper air soundings. The closest meteorological station that has upper air soundings in addition to surface observations is Amman Airport; therefore three years (2007–2009) of hourly meteorological parameters from Amman Airport were used in AERMOD modeling.

Terrain

The area where the cement project is proposed has a generally flat terrain with no nearby communities. The closest community is Alqutraneh, which is located twenty kilometer to the West (upwind) of the proposed project site.

Predicted Concentration of Gaseous Pollutants

The impact of the project on the gaseous air pollutants including carbon monoxide, sulfur dioxide, nitrogen dioxide were estimated (Table 5).Based on the results, it is clear that gaseous pollutants are well below the Jordanian Standards for ambient air quality as reported in JS-1140/2006.

Predicted Dust Concentration

Predicted TSP concentration as estimated using AERMOD and corrected for the background are presented in Fig. 1 and Fig. 2. Fig. 1 shows the highest predicted 24-hrs concentration (worst case) in the vicinity of the project. It is clear that the 24-hrs TSP concentration is in compliance with the Jordanian Standard for ambient air (260 $\mu g/m^3$, JS-1140/2006). The TSP concentration was noticeably high at the quarry "red-circle in the graph center", which is expected because it is basically the main dust source in the project. Fig. 2 shows that predicted annual TSP concentration is in compliance with the Jordanian standard for ambient air (75 $\mu g/m^3$, JS-1140/2006).

Predicted PM_{10} Concentration

The highest 24-hrs and annual PM_{10} predicted concentrations corrected to the background are presented in Fig. 3 and Fig. 4, respectively. It is evident that PM_{10} concentration in the vicinity of the cement project will be

Table 5. Maximum predicted concentration for gaseous air pollutants within 2000 m from the cement project compared against Jordanian standards for ambient air quality (JS-1140/2006).

| Gas	SO_2 (ppm)			NO_x (ppm)			CO (ppm)	
Duration	8-hrs	1-hr	Annual	24-hrs	1-hr	Annual	24-hrs	1-hr
Maximum Predicted Concentration	0.007	0.009	0.005	0.02	0.042	0.008	0.026	0.086
Jordanian Standard	9	26	0.05	0.08	0.21	0.04	14	0.3

in compliance with the Jordanian standard of ambient air (JS-1140/2006), where annual PM_{10} is well be below the annual standard (70 µg/m^3) and the 24-hrs PM_{10} is well be below the 24-hrs standard(120 µg/m^3).

By looking again at Figs. 1–4, it is evident that the highest daily dust concentration is experienced by points located to the North-East of the project. This implies that South-Westerly wind (such as Khamaseen) result in high dust concentration. This observation has to be considered in deciding where to locate the factory, service units, and employee housing.

### Predicted PM₂.₅ Concentration

We have used AERMOD to predict the impact of the project on $PM_{2.5}$ concentration in its surrounding. Sources that contribute to $PM_{2.5}$ emissions are mainly Kiln, Clinker Cooler, and Cement Mill. The quarry does not emit $PM_{2.5}$, because it involves mechanical processes that produce coarse. particles. $PM_{2.5}$ is produced as a result of combustion,
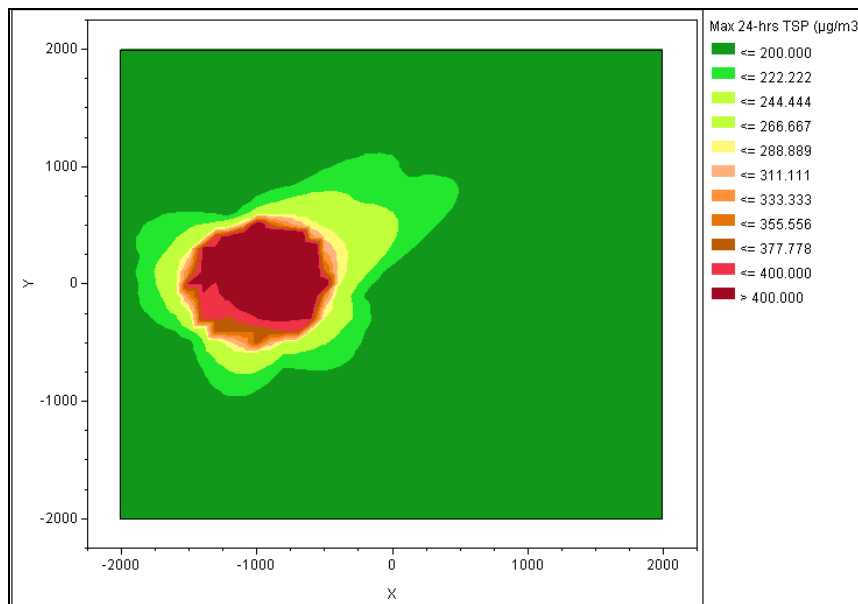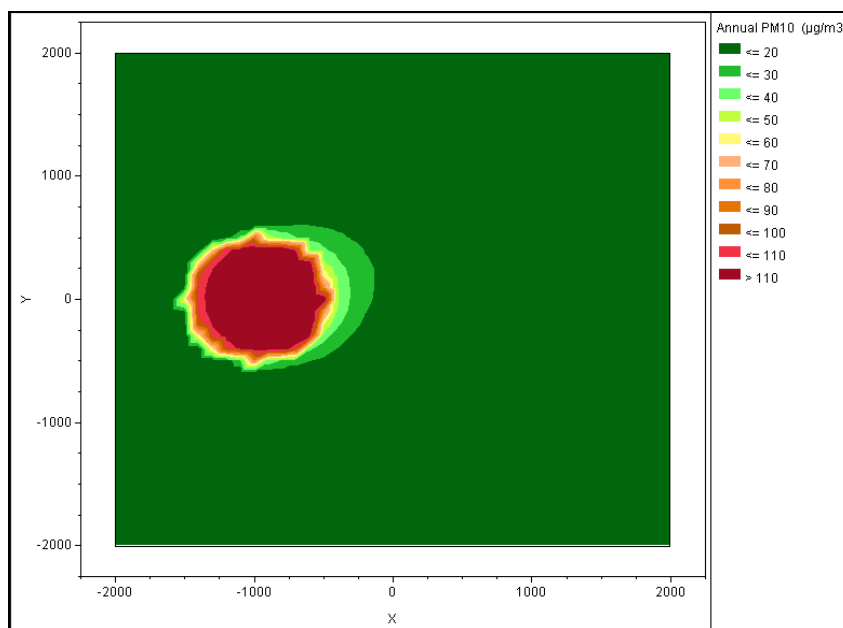

Fig. 1. The highest 24-hrs TSP concentration in the vicinity of the cement project. The x-axis is oriented West (left)-East (right). The quarry is modeled as a circle with 500 m radius and centered 700 to the west of the kiln which is assumed to be located at the origin (0,0).
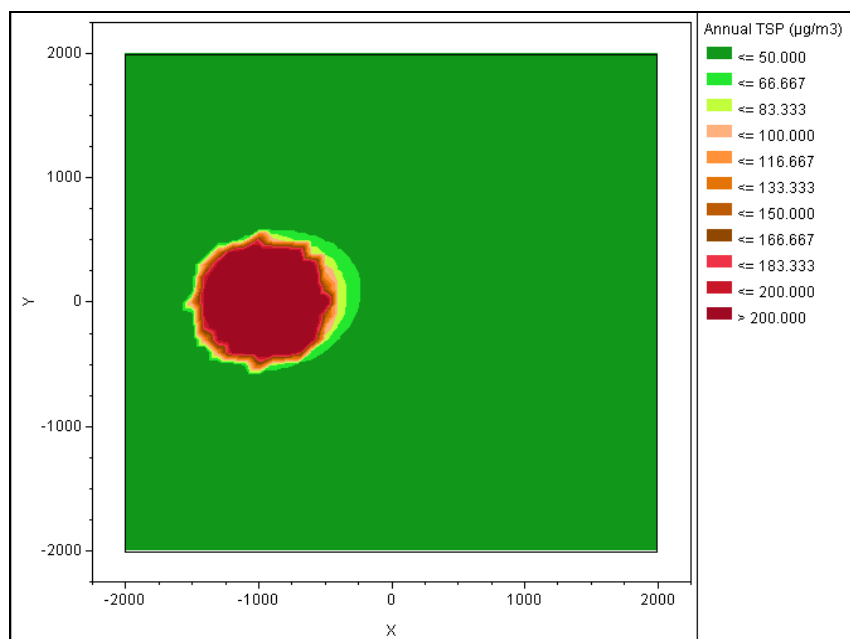
Fig. 2. Annual TSP concentration in the vicinity of the cement project. The X-axis indicates West-East direction. The quarry is modeled as a circle with 500 m radius and centered 700 to the west of the kiln which is assumed to be located at the origin (0,0).
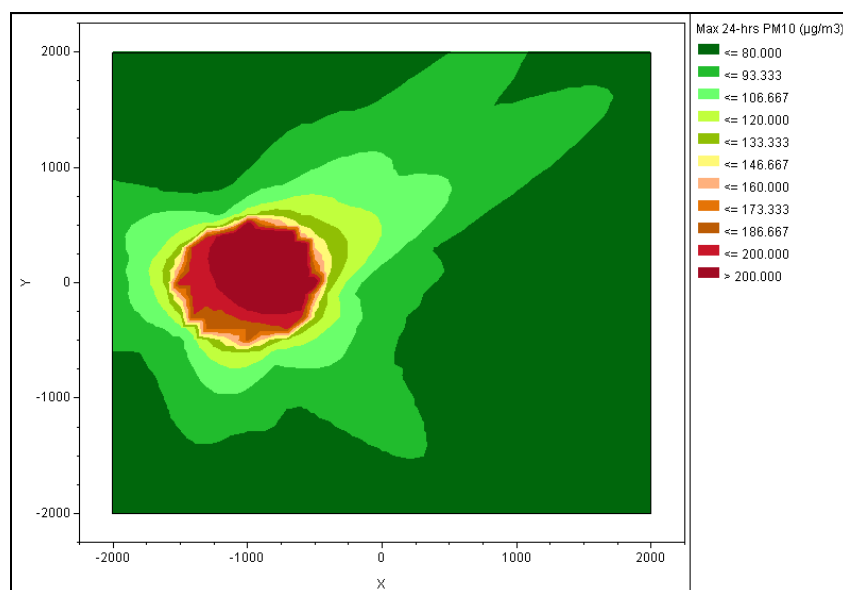
Fig. 3. The highest 24-hrs PM_{10} concentration in the vicinity of the cement project. The X-axis indicates West-East direction. The quarry is modeled as a circle with 500 m radius and centered 700 to the west of the kiln which is assumed to be located at the origin (0,0).

Fig. 4. Annual PM_{10} concentration in the vicinity of the cement project. The X-axis indicates West-East direction. The quarry is modeled as a circle with 500 m radius and centered 700 to the west of the kiln which is assumed to be located at the origin (0,0).

condensation of hot vapor, and/or chemical reaction. The highest 24-hrs and annual $PM_{2.5}$ concentrations corrected to the background are presented in Fig. 5 and Fig. 6, respectively It is clear that $PM_{2.5}$ attains the Jordanian 24-hrs and annual standards of 65 and 15 μg/m³, respectively (JS-1140/2006).

Above results were obtained assuming that the factory will use fuel oils as a fuel source. Similar results for dust, carbon monoxide, and nitrogen dioxide will be obtained if natural gas is used. However natural gas is preferred because

it emits no sulfur dioxide, less hydrocarbons and less soot.

Impact during Enclosure Phase

Main pollutant emitted from this stage is dust (TSP and PM_{10}) which is emitted from the demolition of the plant and the rehabilitation of the quarry and other units. Gaseous pollutants are also emitted from construction vehicles such as loaders, hummers, scrubbers, and vehicles used to transport project personnel. The impact of this stage is temporary and limited to the project site.
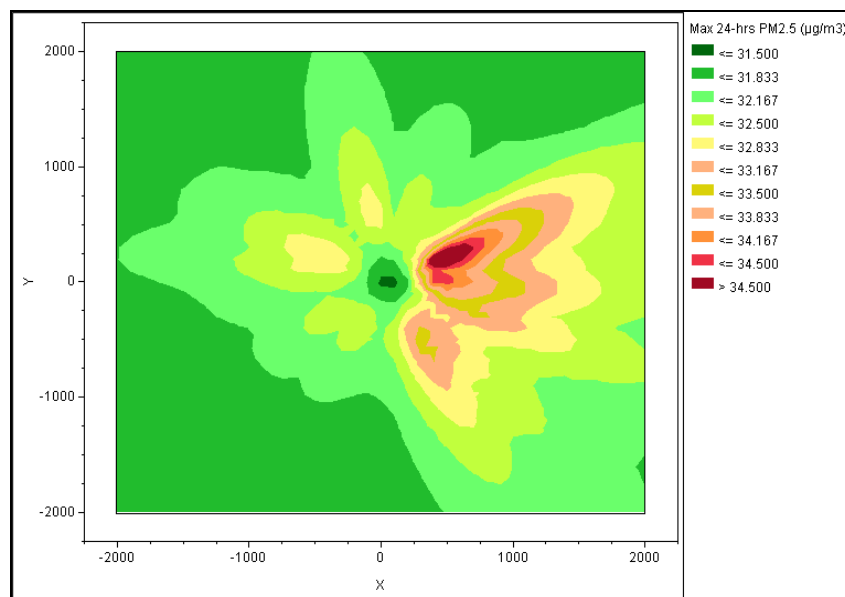
Fig. 5. The highest 24-hrs $PM_{2.5}$ concentration in the vicinity of the cement project. The X-axis indicates West-East direction. The quarry is modeled as a circle with 500 m radius and centered 700 to the west of the kiln which is assumed to be located at the origin (0,0).
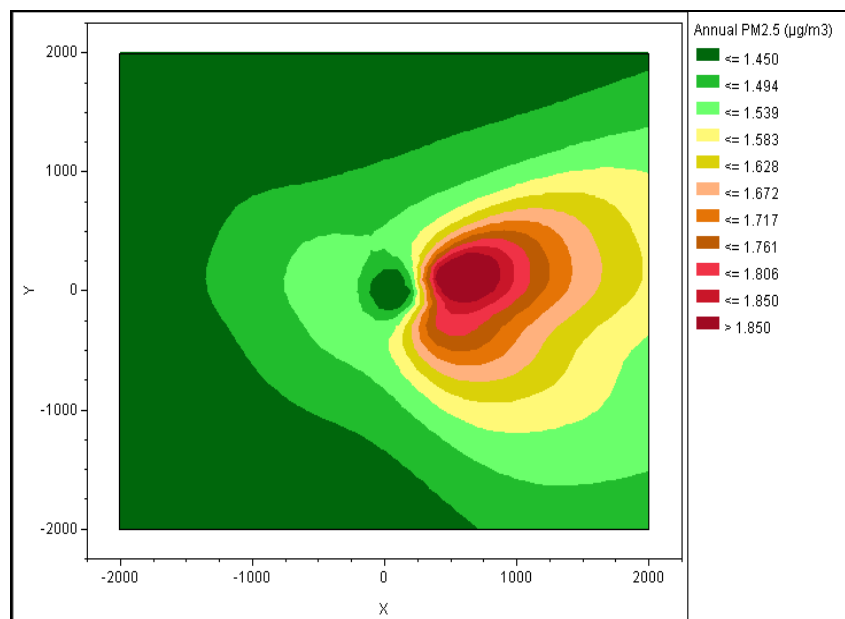
Fig. 6. Annual $PM_{2.5}$ concentration in the vicinity of the cement project. The X-axis indicates West-East direction. The quarry is modeled as a circle with 500 m radius and centered 700 to the west of the kiln which is assumed to be located at the origin (0,0).

Environmental Management Plan

Dust Control Equipment

The emissions of particulate matters from all the units will be limited to 50 mg/Nm^3 in order to ensure healthy air quality in the vicinity of project. Details of stacks and proposed dust control equipments are presented in Table 6. To control the fugitive emissions, the following measures are proposed:

- All the conveyors will be provided with conveyer covers and hoods to offset any trapping of material in wind stream.

- The sprinkling of water will be done along the internal roads in the plant in order to control the dust arising due to the movement of vehicular traffic;
- All the workers and officers working inside the plant will be provided with disposable dust masks; and
- Thick greenbelt will be developed around the plant to arrest the fugitive emissions.

Gasses Control Equipment

- The cement kiln has to be designated as best available

Table 6. Proposed dust control equipment.

Area	Control Equipment	Efficiency (%)
Packing Plant	Bag Filter	> 99.98
Raw Mill/Kiln System	Bag House	> 99.98
Raw Mill Hopper	Bag Filter	> 99.98
Transfer Points	Bag Filter	> 99.98
Blending Silo/Kiln Feed	Bag Filter	> 99.98
Venting of Auxiliaries	Bag Filter	> 99.98
Clinker Storage	Bag Filter	> 99.98
Cement Mill Hopper	Bag Filter	> 99.98
Cement Mill	Bag House	> 99.98
Cement Silo, Bucket Elevator and Auxiliaries	Bag Filter	> 99.98
Cement Silo Top	Bag Filter	> 99.98
Clinker Cooler	ESP	> 99.98
Crushing Plant	Bag Filter	> 99.98

control technology (BACT) for the control of SO_2. The highly alkaline conditions of the kiln system enable it to capture up to 95% of the possible SO_2 emissions.
- Atmospheric Fluidized Bed Combustion (ACFBC) Boiler should be installed at the power generation unit in order control the emissions of SO_2;
- Regular monitoring and continuous auto regulation of fuel and air by automatic combustion control system is encouraged in order to ensure complete combustion and to reduce emissions of CO;
- Generation of NO_x gases depends on the combustion temperature. NO_x can be reduced through:
  i)   stable kiln operation (reduces long term NO_x emissions);
  ii) burner configurations for the rotary kiln;
  iii) staged combustion for precalciner kilns; and
  iv) recirculation of the flue gas (oxygen deficient air in the rotary kiln).

Emission Control Measures

The following measures shall be taken:
- Online particulate and gasses monitor will be installed for Kiln/Raw mill stack in order to provide instantaneous measurements for TSP, PM_{10}, $PM_{2.5}$, CO, SO_2, and NO_2;
- Process interlocking system will be provided to trip off the complete system in case of raise in temperature of the gases and dust particulate across the glass fibre bag house and bag filters, which will trip the entire systems.
- Fugitive dust will be me measured continuously at two locations;
  i) Furthest point to the west of the project (upwind) in order to establish reference point
  ii) Furthest point to the east of the project (downwind) in order to assess the impact of the project on ambient dust.

CONCLUSIONS

This paper presents predictions of air pollutants(dust, SO_2, NO_x and CO) emitted from a proposed cement factory to be constructed 120 km South-East of Amman, the Capital

of Jordan .AERMOD and local meteorological data were used to predicted concentrations of major air pollutants in the vicinity of the project in order to ensure compliance with the Jordanian standards for ambient air quality reported in (JS-1140/2006). Our findings indicate that after the implementation of the proposed project, concentrations of air pollutant are found to be well below the permissible Jordanian Standards for ambient air quality. Therefore, the proposed activity is not likely to have any significant adverse impact on the air environment in the vicinity of the proposed project. However, The TSP concentration is expected to be high at the limestone quarry, which provides the factory with its main raw material, because it generates lots of dust as a result of rocks mining. Water sprinklers, trees planting, and roads routinely sweeping, are among the mitigation measures that that factory have to implement in order to minimize fugitive dust in the vicinity of the factory and the quarry.

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