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Air Quality and Health Impact of Cement Industry on Urbanized Rural Areas

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Abstract

Criteria air pollutants: PM_{10}, CO, SO_2 and NO_2, as well as general meteorological conditions were monitored for the first time ever at five locations in and around the cement industry zone situated in Northern Lebanon in and around the town of Chekka. Two Environmental Monitoring Stations were deployed to survey five locations for intermittent periods of two weeks each from December 2002 to January 2004. Data collected showed that EPA air quality standard levels of SO_2, and PM_{10} were exceeded in more than one location and for long periods of time during the dry season. Levels and locations of measured pollutants were in agreement with the dominant wind directions, and the meteorological conditions. Numerical modeling using CALPUFF allowed the development of scenarios for the fate and transport of smoke stack emissions. Results have confirmed that the industrial plants smoke stacks do not account for more than 10 to 20% of the measured levels of SO_2 and PM_{10}. The rest is attributed to secondary sources at the mills, quarries, and the private power plants operating within the industrial compounds. The health impact on the immediately exposed population was estimated. The different stakeholders were engaged in a series of facilitated meetings which resulted in the creation of a first of a kind tri-partite environmental partnership between local municipalities, the industry, and the Ministry of the Environment for the management of air pollution.

Keywords: Air pollution; criteria air pollutants; cement industry; health impact; cooperative environmental management.

Introduction

"The World Health Organization (WHO) estimates that every year 800,000 people die prematurely from lung cancer, cardiovascular and respiratory diseases caused by outdoor air pollution worldwide. Other adverse health effects include increased incidence of chronic bronchitis and acute respiratory illness, exacerbation of asthma and coronary disease, and impairment of lung function." (World Bank, 2003). Whereas the industrialized world in North America and Europe has fully realized the importance of airborne pollution and its effects on public health and the environment, countries in transition such as Lebanon have not yet developed the necessary awareness nor the administrative and legislative mechanisms by which air pollution can be controlled and reduced in a cost-effective way.

The U.S. Environmental Protection Agency (EPA, 2005) in its national ambient air quality standards (NAAQS) identifies the primary or criteria air pollutants as: sulfur dioxide, particulate matter (PM10 and PM2.5), nitrogen dioxide, carbon monoxide, ozone, and lead. Recent results of a large epidemiological study on the impact of air quality, particularly long term exposure to particulate matter (Pope et al., 1995 and 2002) are now available and can be used for an estimate of health impacts of air pollution. Levy et al. (1999 and 2000) have used these results to develop a methodology and a damage function model for deriving morbidity outcomes, and have applied it to calculate premature deaths and other health impacts in New England due to two power plants emissions. Other studies have linked spikes in deaths from pulmonary related complications directly to spikes in air pollution. These studies were carried out in widely divergent major cities such as Athens, Sao Paolo, Beijing, and Philadelphia (Health Effects Institute, 1995). The World Health Organization (WHO, 1996) and the American Lung Association (ALA Press Release, 2002) have singled out particulate matter as the major culprit in the life-shortening effect of air pollution. With no threshold as to levels of exposure, it was found that mortality can increase by up to 4% from long term exposure to a 10 $\mu g/m^3$ increase in the annual average of particulate matter (PM_{10}). Particulate matter levels are usually below 50 $\mu g/m^3$ in American and Western European cities but can reach more than twice that level in some other parts of the World (WHO, 1994).

In Lebanon, the different environmental stake holders have recently started to realize the seriousness of air pollution problems mainly in urban areas and around some industrial zones. To date of the work reported in this paper very limited data on air quality was available from field measurements carried out by local universities and some other non governmental organizations (Chaaban, 1996; M. El-Fadel 2000, 2001 and 2002; Karam 1999, 2002 and 2005). Data collected in these previous works spanned short periods of time of the order of hours or days. Proper analysis requires long periods of air quality measurements correlated with general atmospheric conditions, and surrounding economic activity.

On the legislative side, the Lebanese Ministry of the Environment has recently adopted or recommended many legislative texts based on international standards and practices (Environmental Laws no 444/2002 and 690/2005), but no field surveys or air quality assessment campaigns were ever carried out. Decision makers have had little to go on in terms of actual pollutant concentration levels and their health impact on the public. In the absence of air pollutants emission models correlated to reliable field data, and proper epidemiological modeling of health impacts, these decision makers are incapable of developing and implementing an effective air quality management plan, even less establish proper air pollutants target reduction levels.

Under these conditions, negative health impacts with their associated economic cost have gone unchecked.

The continuous deterioration of air quality in Lebanese industrial and urban areas, and the lack of effective emissions control policies have resulted in unresolved conflict situations between grass roots organizations, municipalities, and environmentalists pitted against governmental agencies, power plants, and large industrial facilities.

In the following we present the results of a project carried out by the Lebanese American University and funded by the United States Agency for International Development, USAID, from September 2002 to February 2004. The objectives were: to monitor the quality of the air in and around the Chekka heavy cement industry region, to introduce the use of computational modeling tools to study the transport routes and fate of pollutants, to estimate the health hazards to the local population, and to catalyze a process through which all stakeholders would join efforts and agree on an action plan to improve environmental conditions in the region.

Field Data Collection Program

Chekka is an industrial city in northern Lebanon on the eastern shore of the Mediterranean Sea. The local availability of raw materials and ease of marine shipping have transformed it into the largest cement production center in the region since 1932. It is located on a very narrow coastal plain bordered to the east by the Koura plateau at 300m altitude. Many villages are located on top of the overlooking hills and eastward within the plateau. A satellite photograph of the geographic region is presented in Figure 1. It shows the locations of the quarries, the cement factories, and the closest villages of Kefraya, Kfar Hazir, Fih, and Enfeh which encircle Chekka.

The dominant wind direction is south westerly to westerly, and the meteorological regime of Lebanon is characterized by a hot and dry season which usually spans from May to October, and a wet season which spans from November to April. During the wet season frequent rainfall and atmospheric humidity act as natural filters that clean the air from pollutants. During the dry season pollutants can build up to high levels in the air given the absence of rain, and the high frequency of atmospheric inversions. These inversions and the particular shielding effect of the topography reduce the natural ability of the air layers to mix thus reducing the diffusion and dissipation of air borne pollution across large masses of air. The sources of pollution were identified as follows: the smoke stacks of the kilns in the two operating cement factories, the power plants of the two main compounds with combined power in excess of 100 MW, the clinker mills inside the same factories, two limestone quarries, and the transport systems: conveyor belts and trucks.

A first field data collection campaign was launched in November, 2002, and was concluded in March, 2003 to establish base line parameters in those regions with the reportedly highest level of pollution. Five locations were selected: one inside the industrial zone at Chekka, and four in the villages around the western perimeter of the industrial zone namely at Fih, Enfe, Kfar Hazeer, and Kefraya. These locations were monitored during the rainy season, for periods of time of one or two weeks in order to confirm baseline measurements, and establish absolute lows. The second data collection campaign spanned from April 2003 to the end of September 2003. A third and last data collection campaign from October 2003 to the end of December 2003 was carried out to complete a full one year cycle of data collection and measurements in the region. Two environmental monitoring stations (EMS) manufactured by ELE were used to collect air quality and meteorological data. They were fitted with CO, NO_2, and SO_2 electrochemical sensors as well monitors for wind speed, wind direction, air temperature and humidity. Two real time dust monitors (Split2 by SKC) were used to measure PM10 concentration. The EMS stations as well as the dust monitors were equipped with automatic continuous data loggers operating at a sampling rate of ten minutes. The air quality data as well as the meteorological data was recorded, and processed in an extensive database for use by this project and others in the country.

Results and Discussion

The data collected on air concentrations of CO, SO_2, and PM10 is presented in Figures 2 through 6 and a summary of air pollution measurements exceeding EPA NAAQS is presented in Table 1.

Carbon Monoxide

With reference to Figures 2 and 3, we can see that the data collected shows consistently very low levels of CO in the air which is an indication of the absence of inefficient combustion processes. All measured levels are way below the EPA 1-hour and 8-hour exposure standards (EPA, 2005), albeit dry season levels are slightly higher than wet season levels as expected.

Nitrous Dioxide

The measurements in the Chekka and Koura region have showed a very interesting phenomenon. While most of the time relatively low measurements are noted below EPA annual average, which probably correspond to normal transportation and industrial activities, we have monitored periods where measurements have jumped to very high levels that are orders of magnitude more than the annual average. These singular events, which extended from a few hours to a few days, seem to correspond to particular industrial activities or accidents. On at least one occasion these measurements were correlated with a cloud of industrial emissions enveloping a Chekka neighborhood, waking up the sleeping residents and causing widespread breathing problems due to excess NO_2 inhalation. These high levels of nitrous oxide have not been correlated with other emissions. Oven temperature problems, or shut down problems in one of the factories are thought to be the direct cause (Table 1).

Sulfur Dioxide

With reference to Figures 4 and 5, the measurements in the Chekka and Koura region have showed a significantly high level of sulfur oxides during the dry season in the three regions under the wind from the factory smoke stacks: Chekka, Enfeh, and Fih. It is interesting to note that levels in Chekka while still unsafe are slightly lower than those of Fih and Enfeh, where the dominant winds seem to be driving most of the gaseous emissions. The observed levels in Enfeh and Fih are four to ten times the EPA limits, thus pointing to a serious health exposure problem.

Particulate Matter PM10

With reference to Figure 6, the measurements in the Chekka and Koura region have showed a significantly high level of PM_{10} in the air with almost all locations exceeding EPA safe exposure limits during the dry season. It is noted that Kfar Hazeer which shielded by the dominant winds with respect to the smoke stacks showed no gaseous pollutants in its air, it has however high levels of PM_{10} due to the proximity of one quarry to its perimeter.

Chekka shows consistently the highest PM_{10} values, being the closest to all sources, and because particulate matter does not get transported by the wind as far as gaseous emissions.

Numerical Modeling

The EPA recommended software CALPUFF (Scire et al., 2000) was selected to develop a computer model for dispersion and diffusion of pollutants from different types of emission sources. In conjunction with CALPUFF, CALPUFF View (Thé et al., 2003) was used as a graphical user's interface that facilitates and organizes input to and output from CALPUFF.

Air pollution dispersion and diffusion modeling was carried out for smoke stack emissions resulting in a data base of scenarios that can be compared with the field data gathered until December 2003. Results have confirmed that the industrial plants smoke stack do not account for more than 10 to 20% of the pollution observed. The rest is attributed to the secondary sources: mills, quarries, and the private power plants operating within each industrial compound. Simulations for PM_{10} dispersion from the quarries treated as area sources has provided ample support to field measured data.

The computer model was used to answer simple as well as complex questions about the possible origin and fate of air pollutants in the region. Hypothetical scenarios have been established and compared to ground level actual measurements in order to assign critical responsibilities. Sample results of the model simulations using actual meteorological data are presented in Figure 7.

The pollution sources considered in the simulation consisted either of point sources (kiln smokestacks) or area sources (quarries) each simulated separately. The point sources represented the two cement factories with two smoke stacks each and the area sources represented a single quarry for each factory. The emission rates for the point sources were set according to the stack characteristics, exit velocity and stack diameter, shown in Table 2 using limit gas concentrations as set by the "Updated Lebanese Standards for the Portland Cement Industry" (Ministry of

Environment, 1997) at : 800 mg/m^3 for SO_2 and 200 mg/m^3 for PM_{10}. The emission rates for the quarries were estimated from ground level measurements of PM10 inside the quarries. It was not possible to establish emission parameters for the mills, crushers, conveyor belts, and power plants due to restricted access.

Ground concentrations for SO_2 and PM_{10} were numerically evaluated at discrete sampling points. Various arrangements of sampling points were considered: (1) distributed uniformly over a rectangular grid, (2) distributed uniformly over a circular grid centered at the point sources and (3) placed at each of the five locations of the Environmental Monitoring Station. The numerical data supported the measured distribution of pollutants and explained the differences in air quality between the different sampling points.

Estimated Health Impact

Pope et al. (2002) provided the strongest evidence to date that long-term exposure to fine particulate air pollution common to many urban and industrial areas significantly increases residents' risk of dying from lung cancer and heart disease. Fine particulate and sulfur oxide–related pollution were associated with all-cause, lung cancer, and cardiopulmonary mortality. Each 10 μg/m^3 elevation in fine particulate air pollution was associated with approximately a 4%, 6%, and 8% increased risk of all-cause, cardiopulmonary, and lung cancer mortality, respectively. Measures of coarse particle fraction and total suspended particles were not consistently associated with mortality. The authors concluded that long-term exposure to combustion-related fine particulate air pollution is an important environmental risk factor for cardiopulmonary and lung cancer mortality. Reference measurements in Lebanese urban areas such as the capital Beirut and other cities have shown that levels of PM_{10} are on average at least 50 μg /m^3 less than in Chekka. Rural areas on the coast and in the mountains have average levels lower by as much as 100 μg/m^3 (Karam and Tabbara, 2004; Karam, 2005). An estimated total of 35,000 people live permanently in the immediate vicinity of the main cement factories in the Chekka region, i.e. within a 5 km radius as shown in Table 2. This population may swell to well over 50,000 in summer vacation time. More than 150,000 would fall within the 10 to 15 km radius at which serious levels of exposure can still be expected depending on weather conditions. Using the results of Pope et al. (2002) it can be conservatively estimated that the population in the immediate vicinity of the Chekka industrial zone has 20%, 30%, and 40% at least increased risks of mortality due to all-cause, cardiopulmonary disease, and lung cancer when compared to the urban population of Lebanon, and about twice that much when compared to the rural population of Lebanon (Karam and Tabbara, 2005). The lack of detailed medical records, and properly documented epidemiological studies, as well as the limited amount of air pollution measurements limits any attempt at a detailed estimation of health impacts. Limited medical records provided evidence that lung cancer mortality is higher than the regional or national average in Fih, and Chekka.

For every single death per year due to air pollution, health scientists have estimated that there are 3.5 hospital admissions for asthma and 3 non-asthma respiratory admissions, 47 respiratory emergency doctor visits, 2,400 asthma attacks, 12,400 restricted activity days, and 26,600 acute respiratory symptom days (Pope et al., 2002). Local doctors in Chekka and neighboring villages have consistently reported higher asthma cases and respiratory related diseases especially among the vulnerable population of the young and old. Environmental NGO's, working in the region have volunteered the estimate of ten deaths per year related to air pollution in the region. In the absence of official life and injury evaluation procedures, it is proposed to use the costs developed for traffic accidents. Using the nationally established traffic accidents economic costs of 50,000 to 200,000 USD for a lost life, and at 500,000 USD for permanent disability, it is possible to conservatively estimate the cost of ten deaths/year and all other air pollution related hospitalizations and medical expenses. The total amount is on the order of 5 million USD per year. The actual economic cost may be much larger than this estimate when the whole area population is included as well as long term cumulative exposure effects are factored in. Air pollution health impacts are cumulative, and the current health status among the resident population is the result of long years of unchecked pollution and unknown environmental conditions.

Cooperative Approach to Environmental Protection

The cement industry has been established in the Chekka region since 1932. The activities of the industry have gone practically unregulated until the creation of the Ministry of Environment in 1995. Since then the ministry has only been able to apply emission controls over the main smoke stacks through a memorandum of understanding that set emission limits to kiln smoke stacks (Ministry of Environment, 1997); all other industry related air pollution sources were left unregulated. A situation of direct conflict has emerged since 1998 between the local municipalities who challenged these partial standards on one hand, the cement industry, and the ministry of environment on the other hand. The conflict has resulted in an administrative stand still and a war of allegations (Karam, 2002) due to the vigorous lobbying of the industry and a weak central government. The results of the study presented in this paper were used to refute all allegations and restart the process of environmental debate by setting it on a scientific footing, thus engaging all stakeholders in a fruitful and goal oriented cooperation. Informal closed meetings were carried out with each stakeholder individually to develop a background for the proposed cooperative approach as well as to confront recalcitrant stakeholders with facts and literally "shame them" into joining the process (Harrison, 1998). Following these, a series of open stakeholders meetings were called for and facilitated by the authors. Different action plan options were discussed at these meetings not without conflict situations arising and the need for long intercessions. As a result of these meetings, the undeniable scientific facts presented, and the inherent educational process it was agreed to form a tri-partite environmental partnership between the local Municipalities, the Association of Lebanese Industrialists, and the Ministry of the Environment to engage actively in the improvement of environmental conditions and to develop and apply a satisfactory air pollution management plan. This process would be the prelude to a cooperative approach to develop up to date environmental legislation and industrial regulations that meet all stakeholders' requirements while preserving the public interest. During the year following the creation of this partnership the two major factories in the region developed environmental management systems and obtained ISO 14000 certification for them. The process has been slowed to a halt recently due to the political instability of the country and the security conditions in the region.

Table 1. Summary Record of Air Pollution Measurements Exceeding EPA Safe Limits

EPA Standards		150 μg/m^3	0.14 ppm	0.053 ppm	9 ppm
Averaging Times		**24-hour**	**24-hour**	**Annual**	**8-hour**
Location	**Date**	**PM_{10}**	**SO_2**	**NO_2**	**CO**
Chekka	January 10th to January 30th	Peaks at 250	Below EPA levels	Peaks up to 20 over more than one week	Below EPA levels
	May 10th to May 20th	Between 250 and 450	Below EPA levels	Below EPA levels	Below EPA levels
	September 5th to September 22nd	Peaks at 170	0.3 to 0.4	Peaks up to 1	Below EPA levels
Enfeh	March 15th to March 21st	Between 200 and 300	Not Available	Not Available	Not Available
	April 20th to May 14th	Peaks at 180	Below EPA levels	Peaks up to 100 over one week	Below EPA levels
	September 12th to October 2nd	Below EPA levels	1.5 to 1.8	Peaks up to 10 over one week	Below EPA levels
Fih	June 15th to July 3rd	Below EPA levels	Below EPA levels	Peaks up to 100 on a single day	Below EPA levels
	August 25th to September 5th	Peaks at 150	1.5 to 1.8	Peaks up to 10 over one week	Below EPA levels
Kfar Hazeer	March 4th	Peaks at 250	Below EPA levels	Peaks up to 2-3	Below EPA levels
	July 4th to August 15th	Varies between 130 to 170	Below EPA levels	Peaks up to 10 over one week	Below EPA levels

Table 2. Emission Parameters for Kiln Smoke Stacks

					Emissions	
Source Label	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Exit Temperature (°K)	PM_{10} (g/s)	SO_2 (g/s)
Cement Factory #1						
SNC-1	87	2.8	7.5	400	9	36
SNC-2	64	2.8	7.5	400	9	36
Cement Factory #2						
HC-1	108.5	5.7	7.5	400	38	152
HC-2	36	3.7	7.5	400	16	64

Table 3. Exposed Population and Distances to Sources of Pollution

Name of Locality	Estimated Population	Distance from Factory 1 (m)	Distance from Factory 2 (m)	Distance from Quarry 1 (m)	Distance from Quarry 2 (m)
Chekka	14839	720	2335	3085	2629
Kefraya	1610	3148	681	3935	859
Enfeh	9704	2155	4939	2960	4782
Kfar hazeer	4066	4429	4925	2177	3711
Fih	3244	5346	7554	3608	6736

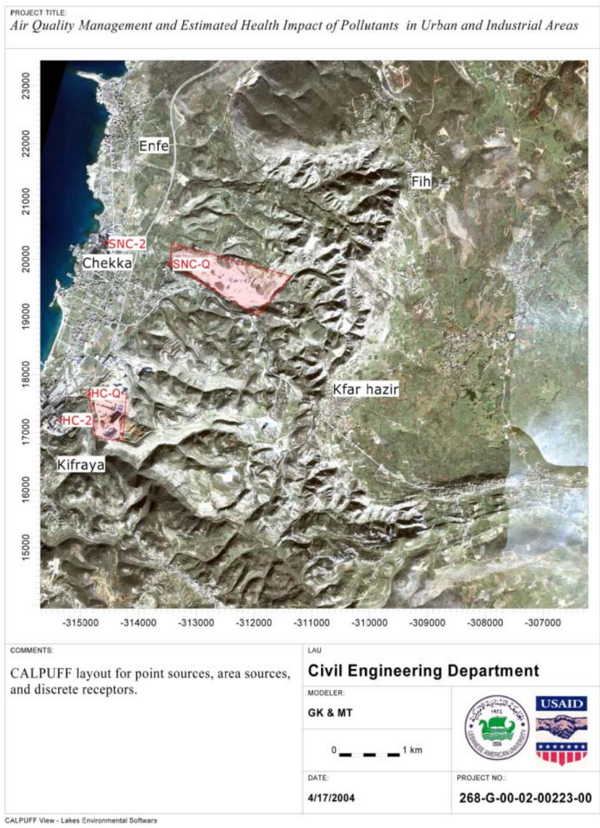

Figure 1. Satellite Photograph of the Chekka Industrial Zone

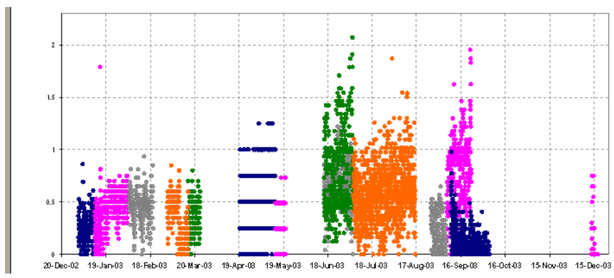

Figure 2- CO Concentration (1-Hour Average, ppm); EPA Standards = 35 ppm

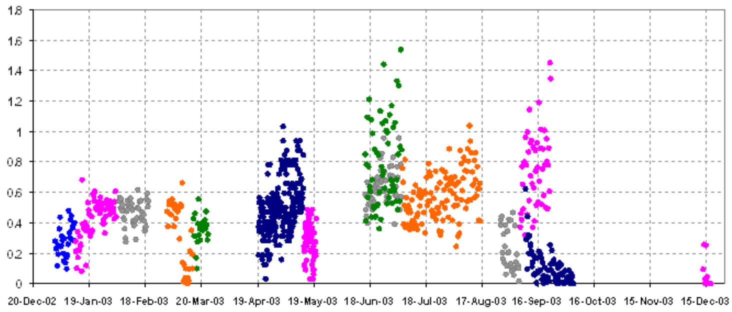

Figure 3- CO Concentration (8-Hour Average, ppm); EPA Standards = 9 ppm

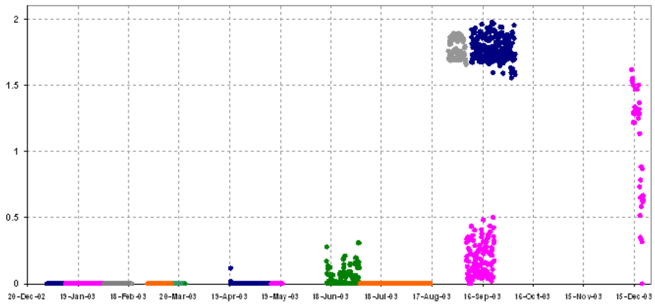

Figure 4- SO_2 Concentration (3-Hour Average, ppm); EPA Standards = 0.5 ppm

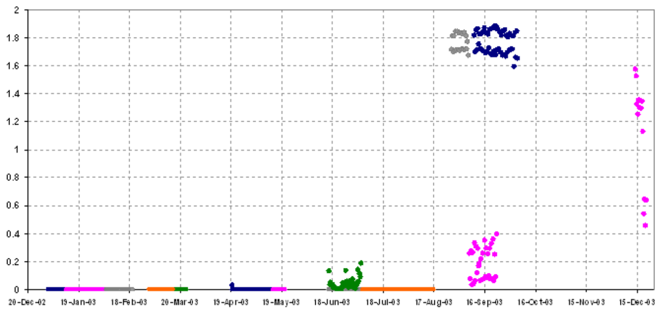

Figure 5- SO_2 Concentration (24-Hour Average, ppm); EPA Standards = 0.14 ppm

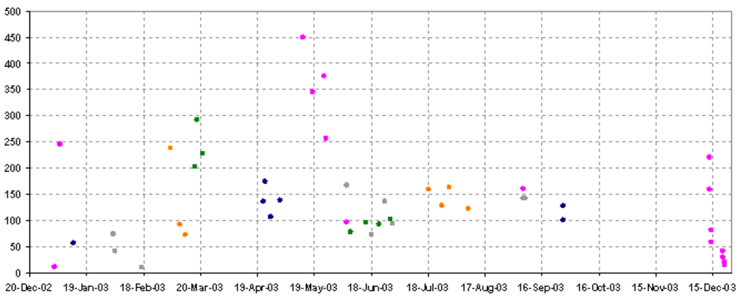

Figure 6- PM_{10} (24-Hour Average,µg/m^3); EPA Standards = 150 µg/m^3

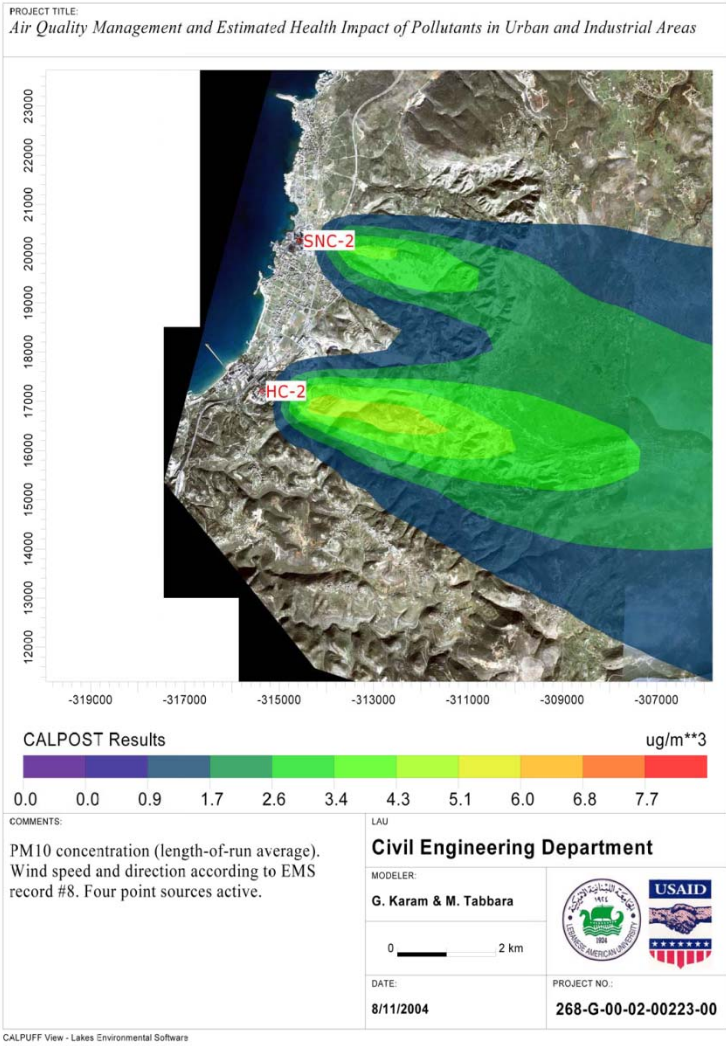

Figure 7- PM10 Dispersion at Fih from 15 June to 5 July 2003.

Conclusions

The levels of airborne PM10, and SO_2 in Chekka and the Koura region were found to be above safe levels as defined by the EPA NAAQS, for at least two months per year.

Activities related to the cement industry were identified as the main source for these pollutants.

The local population was found to be subject to higher risks of mortality by cardio-pulmonary diseases and lung cancer due to air pollution exposure than the average Lebanese population. The direct economic cost to the region was estimated to exceed USD 5 million per year.

The results of this first time ever study were used to engage successfully a cooperative approach to environmental protection between all stakeholders using the techniques of “talking with the donkey”.

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