Health risk from exposure to industrial air pollution for a point source

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RESUMEN

La evaluación del riesgo a la salud de poblaciones expuestas a emisiones tóxicas provenientes de fuentes contaminantes industriales se realiza con el fin de proponer estrategias alternativas de solución o mitigación concordes con las preocupaciones sociales y económicas de la población. En este trabajo se determinan los efectos crónicos no cancerígenos causados por emisiones de SO_2 a través de la metodología *Evaluación de Riesgos a la Salud,* validada por la EPA, que se basa en las concentraciones del contaminante en el aire alrededor de una fuente determinada. Para determinar la distribución de concentraciones se utilizó el modelo gaussiano ISCST con datos meteorológicos de siete días. Los resultados de la simulación indican que el área de mayor concentración de SO_2 se localizó en el arco comprendido entre el sur y el suroeste y en menor medida hacia el sur-sureste de la fuente de referencia. Para la evaluación de la exposición se supusieron dos dosis de referencia, una fuerte y la otra atenuada, equivalentes a una exposición a los niveles máximos permisibles establecidos por la norma correspondiente en períodos de un año y 24 horas. La población supuesta se dividió en tres categorías: trabajadores de la planta industrial donde se localizará la fuente de emisión, los residentes adultos de los alrededores de la planta y los niños menores de 12 años. Los resultados indican que los grupos de mayor riesgo para las *Dosis de Referencia* consideradas son los niños y los trabajadores. La zona de mayor impacto y riesgo se localizó en la dirección sur-suroeste de la referencia. Los Cocientes de Peligro calculados suponen que la población está expuesta a la concentración promedio del sitio por un período de 30 años en el caso de los trabajadores de la planta, y de 75 y 12 años para residentes y niños en los alrededores del sitio, respectivamente.

PALABRAS CLAVE: Riesgo a la salud, exposición, compuestos tóxicos, contaminación atmosférica, toxicología.

ABSTRACT

Health risk to a population exposed to toxic air emissions from industrial sources was evaluated, in order to suggest mitigation strategies according to the social and economic situation. We estimate the chronic noncancer risk due to SO_2 emissions using the EPA-validated *Health Risk Assessment* methodology. The concentration distribution around the source was simulated with the Gaussian ISCST model using real meteorological data for seven consecutive days. The area with the highest concentration of SO_2 was found in the south to southwest direction. For exposure evaluation, two Reference Doses were considered, one strong and the other attenuated. Exposure was evaluated for industrial workers inside the facility containing the emission source, for residents in the neighborhood of the source, and for children under twelve years old.

The groups with the higher risk from the *Reference Doses* were children and industrial workers. The area with the highest risk and impact was towards the south-southwest from the reference source. The estimated Noncancer Hazard Rates indicate risk for the industrial workers exposed to average concentrations for a thirty-year period. In the case of children the period is twelve years, and seventy-five years in residents.

KEY WORDS: Health risk, exposure, toxic compounds, air pollution, toxicology.

INTRODUCTION

Since 1930, in some cities around the world, there have been episodes of extreme high levels of concentration of atmospheric pollutants during several hours or days. The major *Episodes of Atmospheric Pollution* are shown in Table I. Special attention should be paid to populations that live within polluted atmospheres, and to the possible effect of certain pollutants on their health.

Obtaining a quantitative relation between overexposure to atmospheric pollution and health effects on a population is not an easy task. It implies the assessment of morbidity and mortality levels for specific diseases, and their link to the atmospheric pollution.

Since 1978, health effects on people exposed to toxic substances or to non-natural substances as well as epidemiological studies in Mexico and around the world have been

Table 1

Pollution episodes and their effects

Place	Date	Pollutant	Effect and Symptoms
Meuse Valley, Belgium	1-5/dec/30	SO_2, (9.6-38.4 ppm)	63 deaths, breast pains, cough, eye and nose irritation, affectation for all the ages
Donora, Pa. USA.	26-31/oct/48	SO_2, Particles (0.5-2 ppm)	20 deaths, breast pains, cough, eye and nose irritation, the old people are affected mainly
Poza Rica, Mexico	24/nov/50	H_2S	22 deaths, 320 hospital attentions, affectation for all the ages
London, UK	5-9/dec/52	SO_2, Particles	4000 deaths
New York, USA	24-30/nov/66	SO_2, Particles	168 deaths

published (Melgar, 1999). Such studies report the acute effect in the morbidity, establishing short-term relations (days) between high levels of pollution and hospital admissions, medical consultations or number of days with restricted activities connected to illnesses. Other studies evaluate the cumulative effect due to the exposure to pollutants during periods from one year to the average life expecting, including the incidence of respiratory diseases and lung function in populations with different concentrations of anthropogenic pollutants. Changes in the daily death rate associated with changes in levels of atmospheric contamination over short periods of time have also been studied. For long periods of time, the mortality change is determined due to the chronic exposure to pollutants.

For Mexico City, Borja *et al.* (1997) show that an increase of 100 $\mu g/m^3$ of TSP (concurrently with SO_2 and O_3) is strongly related to an increase of 6% in mortality. An increase of 100 ppb of O_3 causes an increase of 2.4% in the total mortality, of 2.3% in cardiovascular disease mortality, and of 3.9% in the mortality of people over 65. In the case of fine particles ($PM_{2.5}$), a 10 $\mu g/m^3$ increase in the concentration levels increases by 1.4% the total mortality, and by 6.9% the child mortality (Borja *et al.*, 1998). In general, an increase in the concentration of PM_{10} has a synergy effect on the presence of other pollutants such as SO_2 and O_3, and the morbidity and mortality percentages are increased. This effect is mainly observed in children and the elderly.

In this paper a human health risk evaluation was performed in order to measure the increase of adverse health effects in people who live close to pollutant emission sources. The inhalation of pollutants in the atmosphere from industry, refineries, power plants, and others raises the probability of people exposed to develop cancer, emphysema, reproductive disorders, or temporary symptoms.

METHODOLOGY

The Health Risk Assessment Methodology validated by the Environmental Protection Agency (USEPA, 1991) was used. For Risk Assessment, four stages are considered: *Hazard Identification*, *Dose-Response Relationship, Exposure Assessment,* and *Risk Assessment*.

As a realistic example an actual industrial plant which emits sulfur dioxide from combustion was considered. The nearby population was divided into three categories: industrial workers inside the facility where the emission source is found, residents in the neighborhood of the source, and children under twelve years old.

Investigation of pollutant toxicity, cancer incidence, exposition, acute or chronic effects as well as target population is the first step towards hazard identification. While there is no evidence that inhaling SO_2 produces cancer, it does produce other effects. For the exposure to sulfur dioxide emissions, inhaling was considered as the main exposure path for potential receptors. The chronic effects on the average lifetime of a person were considered.

To determine how the exposure to different levels of a pollutant changes the probability of occurrence and the severity of health effects, a Dose-Response Relationship is used.

Two types of Dose-Response Relationship have been established. *(1) The Dose-Response Relationship for cancer,* and *(2) Dose Response Relationship for noncancer effects*.

In this first case EPA assumes that zero-risk exposures do not exist, nor is there a *threshold* level. They also consider that this relationship is lineal and that for each unit of increase in exposure (dose) there is an increase in the probability of suffering of cancer (response). This relationship is known as the Slope Factor.

For noncancer risks, a dose may exist before adverse effects happen, therefore there is a threshold dose known as the Reference Dose (RfD). It represents the maximum dose of a pollutant inhaled or ingested by weight unit and by day (mg/Kg-Day), to which a person can be exposed without suffering adverse effects on health. It is understood that natural mechanisms of protection will repair any damage caused by the pollutant at lower doses. However, it is known that the Dose-Response Relationship varies depending on the pollutant, the individual sensibility and the kind of effect on health.

The *Integrated Risk Information System* (IRIS) and the *Health Effect Summary Tables* (HEAST) do not report a Chronic Reference Dose (RfDi) for SO_2. Therefore air quality standards, that is, the annual average maximum concentration of 0.080 mg/m^3 (80 μg/m^3) and the average concentration in 24 hours of 0.34 mg/m^3 (340 μg/m^3), were considered as Reference Dose values, assuming that an exposure to such levels during the lifetime of a person will not have adverse effects on health. These values were taken from the Official Mexican Standard (NOM-022-SSA1-1993).

When those values were used in the equation with the lower value of CDI (equation 5, see below), an estimation of RfD_i for SO_2 was obtained. The strong and attenuated reference values were calculated by equations (1) and (2) respectively:

$$RfD_i = 0.28969\ (0.08) = 0.023175 \text{ mg/kg.-day} \quad (1)$$

$$RfD_i = 0.28969\ (0.34) = 0.098495 \text{ mg/kg.-day} \quad (2)$$

Such values are tentative.

Exposure Assessment

The quantification of the exposure to the chemical substances of interest is estimated from the Chronic Daily Intake (CDI), expressed in units of mg/Kg.-day:

$$CDI_i = \frac{[C_{SO2,air}][LAF][AIR][ET][EF][ED]}{[ABW][AET]}, \quad (3)$$

where CDI_i is the Chronic Daily Intake (by inhalation) of SO_2 [mg/kg.-day]; C_{SO2} is the concentration of SO_2 in the air [mg/m^3]; LAF is the nondimensional Lung Absorption Factor; AIR is the Air Inhalation Rate [m^3/h]; ET is the Exposure Time [h/day]; EF is the Exposure Frequency [d/year]; ED is the Exposure Duration [years]; ABW is the Average Body Weight of the people exposed [Kg] and AET is the Average Exposure Time [days].

In equation 3 CDI_i depends on many factors that vary according to the type of receptor. The potential receptors were industrial plant workers and adults and children who live near the emission source. The values of the variables are shown in Table 2.

The values are introduced in equation 3, which depends only of SO_2 concentrations. The equations for each receptor are as follows:

Industrial workers: $$CDI_i = 0.28999\ [C_{SO2}] \text{ mg/kg-day} \quad (4)$$

Adult Residents: $$CDI_i = 0.28969\ [C_{SO2}] \text{ mg/kg-day} \quad (5)$$

Child Residents: $$CDI_i = 0.55555\ [C_{SO2}] \text{ mg/kg-day} \quad (6)$$

To estimate the amount of emission of the pollutant in the air in a specific period of time, either measurements or estimated emission factors for the type of process and fuel may be used. The monitoring equipment samples air from the stacks of ovens and boilers and measures the amount of pollutants. Mathematical models, such as dispersion models are used to calculate the concentration of pollutant at different distances and directions from the emission source. The models take into account the meteorological conditions (wind speed and direction, temperature, atmospheric stability, and mixing layer height), as well as the physical characteristics and parameters of emissions (height and diameter of the stacks, temperature and speed of the gas flux, etc.). A detailed database for all those parameters is provided in Appendices A and B.

Concentrations of SO_2 from a point source were determined assuming a receptor every 15° and 200 meters around the source. The simulations were carried out using the ISC (Industrial Source Complex) Gaussian model developed and validated by EPA (USEPA 1995, 1995a) in its short time version. The ISC-ST is a relatively simple model that may be used for dispersion simulations of pollutants such as particular matter, sulfur dioxide, nitrogen dioxide, or carbon monoxide from point sources. The model does not consider chemical reactions between pollutants nor dry wet deposition.

Table 2

Exposure Factors

Parameter	Units	Industrial Plant	Residents	
		Workers	Adults	Children (< 12 y.)
AI, Average Inhalation♦ +	(m^3/h)	3.8	2.6	2.5
ET, Exposure Time♠	(h/day)	8	8	8
AIR, Air Inhalation Rate† = AI * ET	(m^3/day)	30.4	20.8	20
EF, Exposure Frequency	(days/year)	250 - average working days a year-	365	365
ED, Exposure Duration ☞	(years)	30 - Average Working Time-	75 -Average Lifetime-	12
ABW, Average Body Weight≠	(kg)	71.8	71.8	36
AET, Average Exposure Time = EF * ED	(days)	10 950	27 375	4380

♦ Average Inhalation (Adams W.C., 1993).
♠ **Workers:** corresponds to the volume of inhaled air by an adult practicing intense physical activity during eight hours a day (work shift). **Adults**: which corresponds to an adult with moderate activity during 8 h/day, which is the estimated time for an average adult directly exposed in the place with the highest concentration. This exposure period suggests open-air activities located in the wind direction. **Children**: This corresponds to a child in an activity higher than normal during 8 hours a day, which is the estimated time that an average child remains in that place.
† Air Inhalation Rate (Layton D.W., 1993)
☞ Average Working Time for Mexican workers.- Average Lifetime (USEPA, 1989)
≠ Average Body Weight (USEPA, 1989).

The more important assumptions for the simulations were as follows:

- Meteorological conditions can affect total impacts by influencing transportation pollutant. In this study, we assume that the regional meteorology is applicable to all receptors and that the seven days of meteorological data are representative of severe conditions along the year. Based upon several studies[1] over four years, we selected the period that represents critical or severe conditions for pollutants transport. Of course we are aware that a region can have different meteorological patterns.
- The emission fluxes from the stacks are assumed constant along the period of the study.
- The model parameters were from plane terrain, urban area, and ground concentrations of pollutants (up to 2 meters above the ground).
- A direct fired heater, named ABA-1, was the reference source for the modeling coordinate system 0,0 (See Appendix A), and 1200 receptor points were established around the reference source from 0 to 10 000 meters distance.

Figure 1 shows the wind directions. Prevalent winds are from north-northeast (frequency: 36 %) and northeast (frequency: 16 %) directions. In both cases the wind speed varies from 3 to 9.5 m/s. We assume that the most impacted area is located in a sector between south and west from the reference source (0,0). Temperature, atmospheric stability, and, mixing layer height data are shown in Appendix B.

Risk Assessment

We quantify the health effects caused by the exposure to toxic substances that produce noncancer risks by the Noncancer Hazard Quotient (HQ). The Hazard Quotient es-

[1] Technical Reports, Environmental Science Management, Numbers: (1996) **GCA96**: 026, 027, 033, 034, 049; (1997) **GCA97**: 001-003, 005-007, 009-010, 012-018, 022-023, 025-026, 030-32, 034-036; 047-054, 059-061, 067, 071, 078, 088-089, 096-105; (1998) **GCA98**: 001-007, 009, 011, 014, 018, 020-021, 027-028, 037, 039, 041-047, 049-050, 054-056, 061, 067, 080, and (1999) **GCA99**: 001-005. Mexican Petroleum Institute, Mexico.

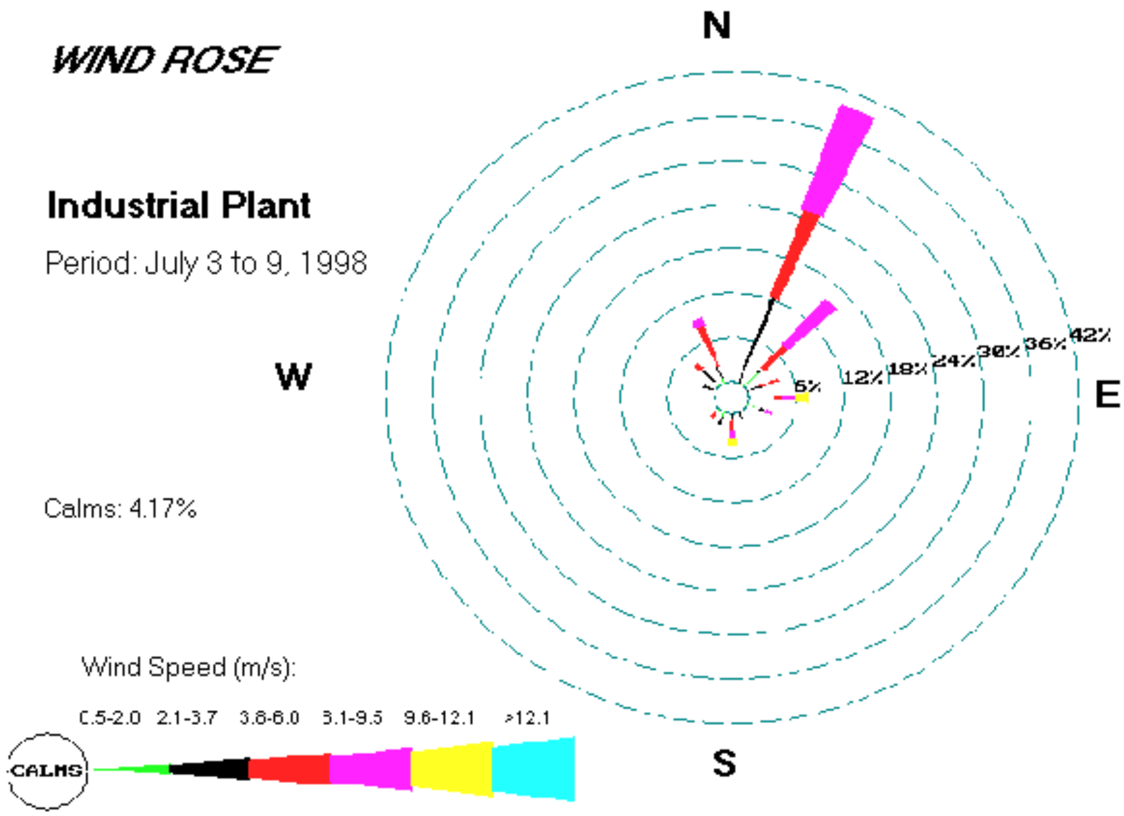

Fig. 1. Wind Rose.

tablishes the relationship between a dose which a receptor may be exposed to, i. e. the CDI, and the RfDi.

$$\mathbf{HQ= CDI}_{SO2} \div \mathbf{RfD}_{SO2} \quad . \tag{7}$$

If the values of HQ are greater than one, the dose exceeds the RfD, and may produce adverse effects. Therefore, when HQ>1.0, a mitigation action is needed to decrease the concentrations that the receptors are exposed to, or to decrease the frequency and the exposure time. If HQ ≤ 1.0 it is not assumed to be necessary to carry out any action.

The Hazard Quotients were determined by substituting the values of RfD from equations 1 and 2 into equation 7. CDI values were obtained from equations 4, 5, and 6, depending on the receptor type. Finally, the concentrations were obtained from the ISC-ST model for different distances from 500 m up to 10 000 m.

RESULTS

From the simulations, the maximum average values of concentrations of SO_2 exceeded the 24 hour standard between 600 m and 3400 m reaching maximum concentrations of 0.55 ppm (1,441 μg/m^3) as shown in Figure 2.

In this study, the highest affectation area was found in the south-southwest direction from the stack considered as the origin of the emissions. The pollution plume shows concentrations above the permissible standards and covers an area of approximately 2000 m^2.

Due to the short period of time considered for this study, only seven days, the reliability of the results of the modeling may be moderate. However, the exercise indicates the area with potential environmental problems under these conditions.

If meteorological conditions are less critical for the good dispersion of pollutants, lower concentrations may be produced. It is suggested to make continuous measurements at the stacks, and to repeat the calculations in order to determine the actual health risks.

The high concentrations may be attributed to the severe meteorological conditions used in this study, to the large amount of sulfur in the fuel, and to the short period, of time, which may affect the influence of meteorological conditions. The estimated values of the Hazard Quotients may be assumed as the worst possible values.

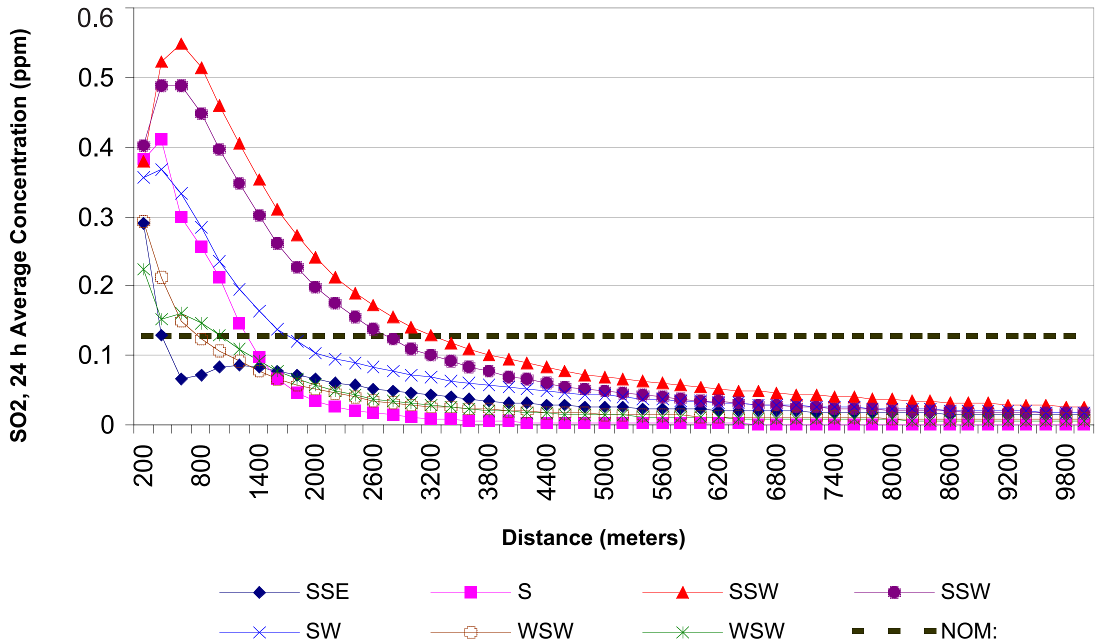

Fig. 2. Profile of SO_2 average concentrations as a result of the simulation with the ISC-ST. Remark: In Mexico, the NOM-022-SSA1-1993 for SO_2 is 0.13 ppm to 24 h

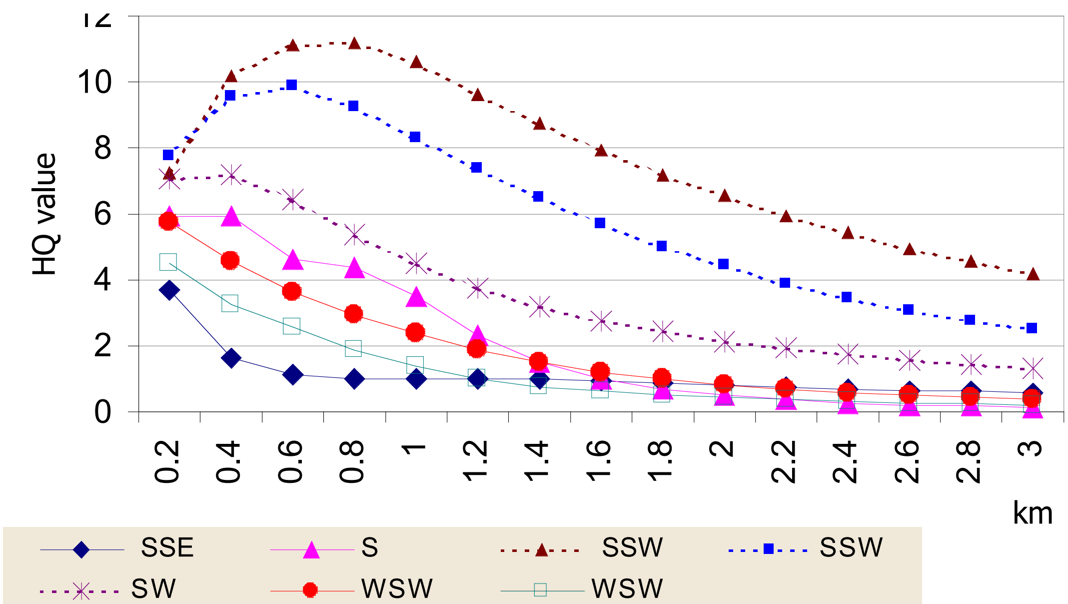

Fig. 3. Workers Hazard Quotients, RfDi (Eq.1).

SO_2 Reference Dose (Chronic effects)

In Figures 3, 4 and 5, the Hazard Quotients estimated with equation 1 for different types of receptors are shown, using the average Official Mexican Standard (0.08 mg/m^3) as a Reference Dose. For the population of industrial workers at the plant, and for the population located in the south - southeast and west-southwest quadrants from the emission source, the Hazard Quotient exceeds unity in 40% of the cases. However, for the south - southwest direction, 100% of the receptor points exceed this value. The maximum value of Hazard Quotient found was 11.17, which suggests that a

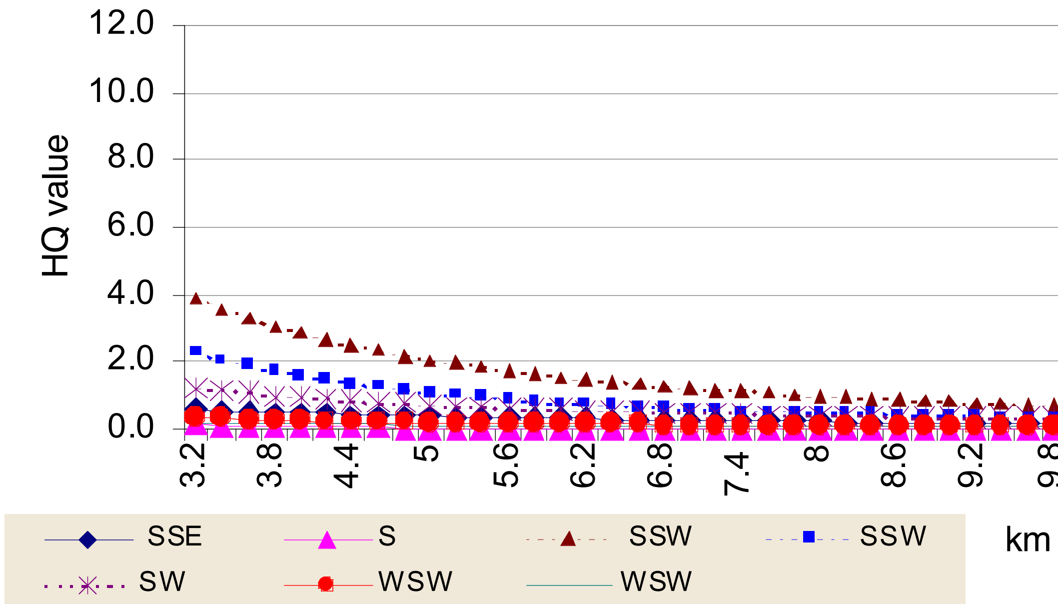

Fig. 4. Adult Residents Hazard Quotients, RfDi (Eq. 1).

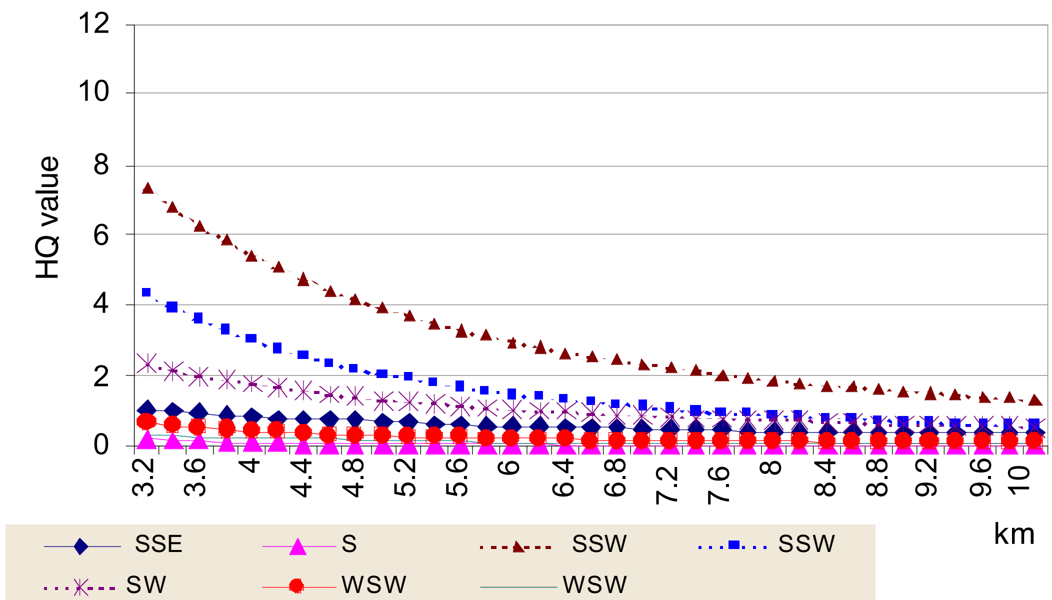

Fig. 5. Children Hazard Quotients, RfDi (Eq.1).

worker who stays during 8 hours in the area may suffer chronic effects due to the concentrations of SO_2. This area is approximately 3 km^2 in the present facility.

Adult residents outside the plant, located 3200 m from the emission source, presented Hazard Quotients higher than unity in the south - southwest direction, but the maximum HQ values were lower than for the industrial workers. Values of HQ >1 are found up to a distance of approximately 7500 m in this direction.

Finally, in the south - southwest direction the value of HQ was above 1.0 in 100% of the cases for children under 12 years old.

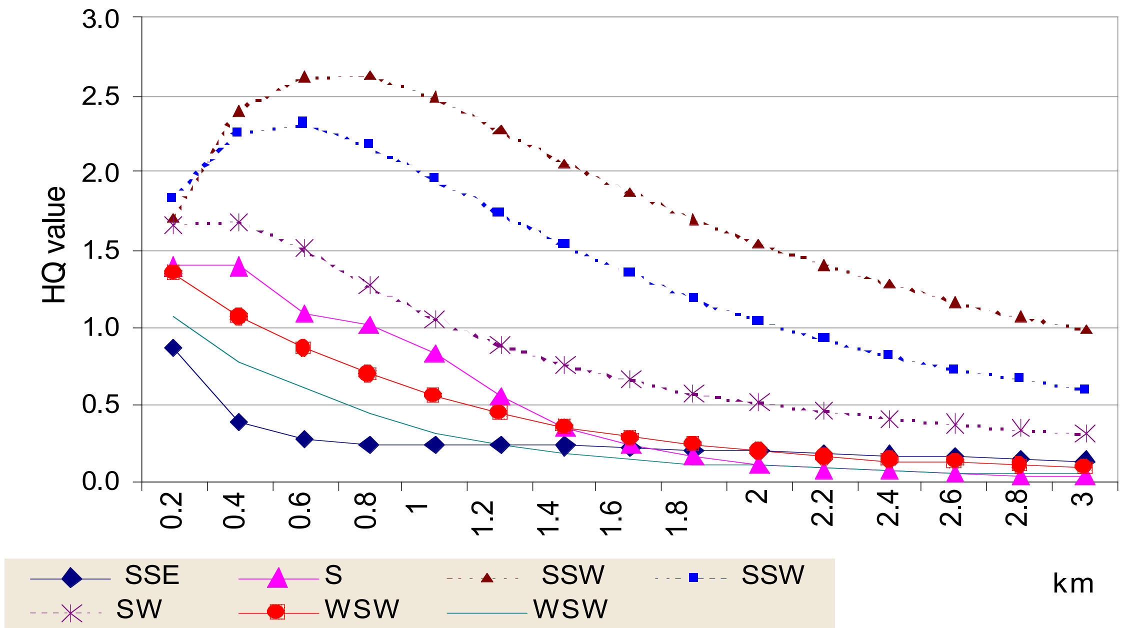

Fig. 6. Workers Hazard Quotients, RfDi (Eq. 2)

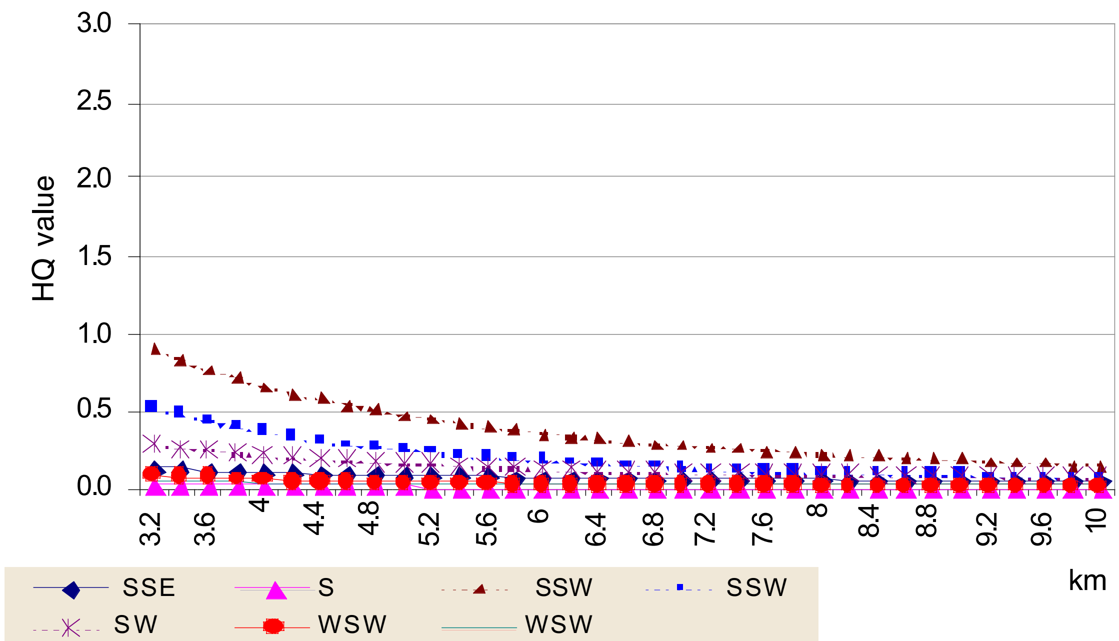

Fig. 7. Adult Residents Hazard Quotients, RfDi (Eq.2)

SO_2 Reference Dose (Acute effects)

In Figures 6, 7 and 8, the Hazard Quotients estimated from equation 2 for different distances from the stack are shown, taking as reference dose the average concentration of SO_2 in 24 hours after the Official Mexican Standard. Unlike the previous case, in none of the cases the values of HQ were over 1.0 for the adult resident group. For the children group, 71% of the receptor points exceeded this value in the south -southwest direction, with 2.44 as a maximum value. However, for industrial workers the situation was different. In 31% of the receptor points HQ>1.0 in the southwest di-

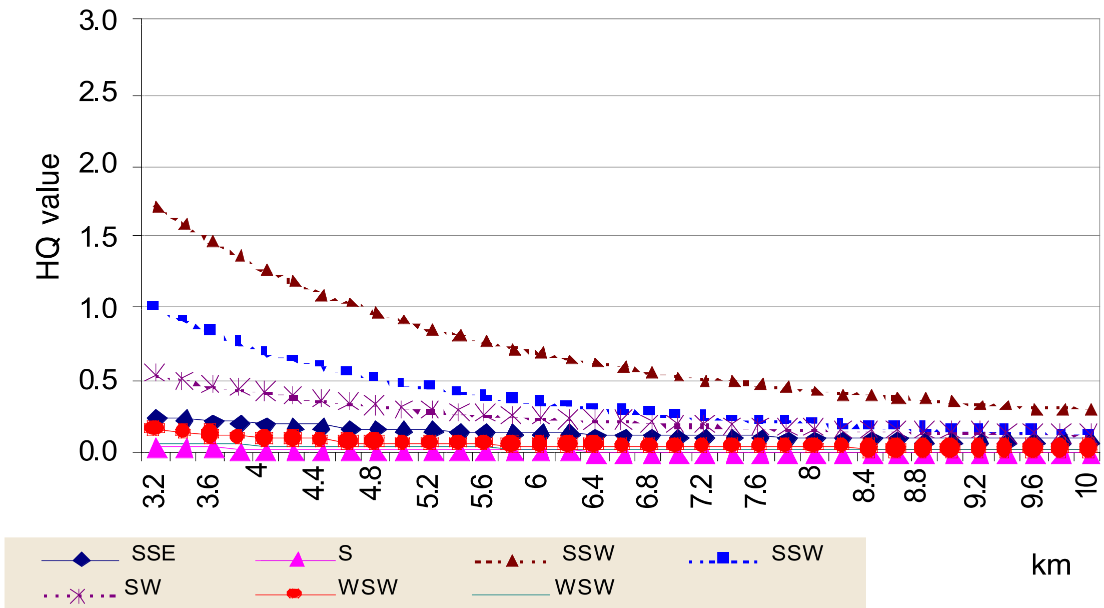

Fig. 8. Children Hazard Quotients, RfDi (Eq. 2)

rection, whereas in the south - southwest direction it exceeded unity in 94% of the receptor points.

Note that the Hazard Quotients are based upon the assumption that the resident is exposed to an average concentration and to severe meteorological conditions for a constant period. The considered exposure time is 30-year in the case of the industrial workers, 75-year for adult residents, and 12 years for children. Actually, in all cases, people are exposed to lower concentrations due to the variability in meteorological conditions and the mobility of people who do not always stay in the same polluted area.

In Table 3 a summary of the results using both Reference Doses for different directions are shown.

Table 3

Summary Results

RfDi [mg/kg-day]	Receptor	Direction	%HQ>1
0.023175	Workers	SSE-WSW	40
	Workers	SSW	100
	Adults	SSW	68
	Children	SSW	100
0.098495	Workers	SW	31
	Workers	SSW	94
	Adults	SSW	0
	Children	SSW	22

CONCLUSIONS

1. The area with the strongest impact was located in the south - southwest direction from the reference stack.
2. Among different groups studied, children and industrial workers were the groups with the higher health risk for both reference doses.
3. It is suggested to have constant monitoring of SO_2 emissions and of meteorological parameters both inside the facility and within its influence zone.
4. It is necessary to undertake further studies in time and under different operation conditions, and with different types of fuel, in order to establish the differences and propose effective control measures.
5. To measure the real exposure, a sample group of industrial workers and children should use personal monitors.

APPENDIX A

Physical characteristics and parameters of emission

Emission Sources	**Height**	**Diameter**	**Temperature**	**Speed.**	**Relative Coord. East**	**Relative Coord. North**	**Qs SO_2**
Units	m	m	°K	m/s	m	m	g/seg
CB-1	21.6	3.00	490.0	16.0	173.0	586.0	302.58
CB-2	21.6	3.00	491.5	17.8	203.0	586.0	339.39
CB-3	30.6	3.03	473.9	18.1	147.0	155.0	365.15
CB-4	30.6	3.03	461.1	17.3	147.0	186.0	355.84
CB-5	30.6	3.03	461.1	16.9	146.0	217.0	352.89
ABA-1*	**27.3**	**4.20**	**658.8**	**11.1**	**000.0**	**000.0**	**175.32**
ABA-2	27.3	4.20	659.8	10.6	20.0	000.0	168.56
VBA-1	39.5	3.68	655.7	13.9	40.0	000.0	220.34
VBA-2	39.5	3.68	655.8	13.7	55.0	000.0	174.39
ABA-51	16.8	1.71	599.1	5.0	-29.0	000.0	10.17
501-I	22.5	2.60	698.1	8.5	75.0	-522.0	43.45
502-I	16.0	0.98	516.1	5.5	95.0	-522.0	0.0
401-I	18.5	1.82	512.1	2.3	25.0	-522.0	0.0
402-I	26.3	1.35	468.1	3.8	5.0	-522.0	0.0
403-I	27.5	1.82	529.1	2.1	20.0	-522.0	0.0
701-I	20.0	1.58	533.1	4.4	35.0	-522.0	0.0
702-I	20.0	1.80	540.1	3.4	55.0	-522.0	0.0
801-I	19.9	1.82	521.1	2.9	84.0	-521.0	0.0
802-I	21.6	1.82	452.1	2.5	64.0	-521.0	0.0
H01-A	32.4	5.00	761.1	2.1	212.0	-428.0	54.31
H01-B	32.4	5.00	761.1	1.7	232.0	-428.0	47.96
501-N	21.2	2.77	588.1	6.5	145.0	584.0	42.56
501-S	21.2	2.77	588.1	6.5	165.0	584.0	38.66
502-II	17.9	1.77	478.1	2.1	85.0	584.0	0.0
401-II	13.5	1.71	583.1	6.3	25.0	584.0	0.0
402-II	11.0	2.01	588.1	8.1	45.0	584.0	0.0
403-II	11.5	1.42	508.1	1.9	65.0	584.0	0.0
404-II	11.5	1.49	473.1	6.0	75.0	584.0	0.0
701-II	12.8	1.74	558.1	3.2	105.0	584.0	0.0
702-II	12.8	1.74	553.1	5.2	125.0	584.0	0.0
2B	43.1	2.69	523.1	5.7	210.0	-274.0	39.88

*Reference stack

APPENDIX B

Meteorological Data

D	t	WD	WS	T	S	ML	D	t	WD	WS	T	S	ML	D	t	WD	WS	T	S	ML	D	t	WD	WS	T	S	ML
3	20	247	1.97	299.8	4	850	5	7	21.7	4.5	299.1	4	600	6	18	40.5	7.2	304.6	4	1650	8	5	338.8	4	293.4	4	300
3	21	41.3	0.9	299	5	0	5	8	23.5	5	298.9	4	1000	6	19	25.8	5.8	304.5	4	1525	8	6	334.3	2.8	292	5	50
3	22	113.2	0.04	298.6	6	0	5	9	23.3	5.3	299.8	4	1025	6	20	21.8	4.6	303.8	4	1400	8	7	292.7	2.1	294.8	4	300
3	23	112	0.01	298.7	6	0	5	10	19.7	5.8	300.9	4	1050	6	21	341.3	4.3	301.8	4	1000	8	8	318	2.7	296.2	4	650
3	24	315.9	2.79	299.3	5	0	5	11	23.6	6.9	301.6	4	1375	6	22	312	3.4	298.1	4	1000	8	9	341.2	3.4	297.1	4	875
4	1	297.8	2.76	299.3	5	0	5	12	23.5	8.2	302.2	4	1700	6	23	37.8	6.1	300.3	4	1000	8	10	344.4	4.3	296.6	3	1100
4	2	335.9	3.11	300.3	4	50	5	13	25.5	7.3	303	4	1575	6	24	22.4	6.8	301.6	4	1000	8	11	342.3	4.5	296.1	3	1150
4	3	22.1	3.43	300.7	4	100	5	14	25	6.6	303.8	4	1450	7	1	15.6	8.3	301	4	1000	8	12	92.4	0	296	3	1200
4	4	22.1	3.15	300.8	4	100	5	15	43.2	6.6	304.2	4	1450	7	2	18.1	7.9	301.2	4	1000	8	13			297		
4	5	28.1	2.83	300.3	5	0	5	16	41.8	6.1	302.7	4	1450	7	3	24.5	6.9	300.9	4	1000	8	14			297		
4	6	223.2	1.03	299.9	5	0	5	17	26.3	5.7	304.9	4	1350	7	4	22.5	6.3	300.6	4	1000	8	15	40	6	299.8	4	1300
4	7	23.4	2.26	299.8	4	200	5	18	24.3	5.5	305	4	1250	7	5	93.2	6.4	299.8	4	1000	8	16	38.8	4.1	299	3	1450
4	8	21.8	2.89	299.1	4	600	5	19	44.1	4.6	304.6	4	1250	7	6	19.6	6.1	299.5	4	1000	8	17	48.9	1.7	298.6	4	1450
4	9	24.1	2.42	299.4	4	750	5	20	91.6	4.8	302.2	4	1250	7	7	16.1	6.9	300	4	1000	8	18	49.4	3.7	298.7	4	1450
4	10	23.1	2.77	300.3	3	900	5	21	108.3	5.8	298.4	4	1250	7	8	337.2	4.8	298.8	4	1050	8	19	43.5	5.9	299.3	4	1450
4	11	25.6	3.09	301.3	3	1025	5	22			298.1			7	9	338.9	5.6	296.5	4	1100	8	20	26.3	4	299.3	4	1450
4	12	24.7	2.64	302.4	3	1150	5	23			298.1			7	10	18.8	5.7	295.3	4	1150	8	21	16.7	3.4	300.3	4	900
4	13	64.6	3.06	303.1	3	1350	5	24			298.1			7	11	18.8	5.7	296.5	4	1150	8	22	18.4	2.9	300.7	5	200

D (day), t (time), WD (wind direction, grades), WS (wind speed, m/sec), T (temperature, °K), S (stability), ML (mixing layer (m).

APPENDIX B

Meteorological Data (continued.)

D	t	WD	WS	T	S	ML	D	t	WD	WS	T	S	ML	D	t	WD	WS	T	S	ML	D	t	WD	WS	T	S	ML
4	14	66.6	3.58	303.7	2	1550	6	1			298.1			7	12	18	5.7	297.5	4	1150	8	23	22.6	2.9	300.8	5	100
4	15	66	3.34	304.1	2	1525	6	2			298.1			7	13	16.6	6	300.3	4	1325	8	24	24.5	3.3	300.3	4	50
4	16	64.7	3.42	304.5	3	1500	6	3			298.1			7	14	19.1	4.7	301.1	3	1500	9	1	22.3	2.4	299.9	5	20
4	17	66.7	4.11	304.3	3	1500	6	4			298.1			7	15	341.6	0.1	301	2	1525	9	2	21.4	2.4	299.8	5	20
4	18	193	3.53	303.8	3	1500	6	5			298.1			7	16	263	4.4	301.3	3	1550	9	3	19.7	2.6	300.1	5	20
4	19	226.7	4.3	302.6	4	1000	6	6			299.1			7	17	157.1	2.1	301.8	3	1550	9	4	23.5	2.6	300.3	5	20
4	20			301.5			6	7			299.1			7	18	178.1	2.4	302.2	3	1550	9	5	113.9	0.2	299.6	6	0
4	21			300.1			6	8			299.1			7	19	202.2	1.8	302.1	3	1500	9	6	42.6	1.6	299.2	6	0
4	22	206.1	2.4	300.1	5	0	6	9			299.1			7	20	109.2	2.3	301.8	4	1450	9	7	312.6	1.5	298.8	5	50
4	23	89.9	1.3	300.3	6	0	6	10			299.1			7	21	19.8	4.5	300.5	4	1200	9	8	41.7	4.1	298.3	4	550
4	24	91.1	0.9	299.6	6	0	6	11	340.3	4.6	299.5	3	1250	7	22	178.6	5.3	298.8	4	1000	9	9	19.1	2.2	298.3	4	1100
5	1	109.3	0.5	299.2	6	0	6	12	336.7	0.6	301.1	3	1250	7	23	92.2	8.2	295.8	4	1000	9	10	43.4	5.7	298.1	4	1250
5	2	112.5	0.5	298.8	6	0	6	13	20.9	5.4	301.3	4	1375	7	24	180.5	8.7	296.9	4	1000	9	11	21	4.4	299.2	4	1300
5	3	89.2	0.6	298.3	6	0	6	14	38.8	6.8	304	4	1500	8	1	178.7	7.9	295.9	4	1000	9	12	19.6	4.1	299.1	3	1350
5	4	90.1	0.4	298.3	5	0	6	15	23.2	6.6	304.5	4	1600	8	2	94.4	9	295.6	4	1000	9	13	23.6	3.6	298.9	3	1275
5	5	26.4	3.5	298.1	4	50	6	16	39.8	7.3	304.6	4	1700	8	3	91.2	8.6	293.7	4	1000	9	14	46.7	5.1	299.8	4	1200
5	6	19.7	4.6	299.2	4	200	6	17	38.5	8	304.3	4	1675	8	4	317.3	3.1	293.5	4	600							

D (day), t (time), WD (wind direction, grades), WS (wind speed, m/sec), T (temperature, °K), S (stability), ML (mixing layer (m).

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