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Original Research

Characterization of environmental risk due to exposure of athletes to atmospheric pollution

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Abstract

Environmental risk assessment (ERA) is a scientific process for evaluating the potential of adverse health impacts resulting from exposure to environmental stress (EPA, 2017). This is a tool for quantitatively estimating and ranking population health impacts from exposure to environmental contaminants. In this context, the present work aims to characterize the health risk of people who develop physical activities in the main avenues of the city of Villa Elisa, province of Entre Ríos, Argentina. In this way, it will be observed whether they are exposed to atmospheric pollutants related to vehicular emissions, more precisely nitrogen dioxide (NO2), sulphur dioxide (SO2) and particulate matter (PM2.5). The ERA methodology used involved, for the exposure assessment phase, the execution of a control census. This was done in order to establish the worst case exposure scenario. Based on this information, air quality measurements were carried out in 4 pre-established zones, using portable measuring equipment. Once the data had been processed, the risk characterisation phase continued in accordance with the ERA procedure. From this work, it was possible to determine the hazard coefficient for exposure to measured pollutants. It was determined that, in the different study areas, the nominal value (Mokhtar et. al, 2014) was not exceeded in the determination of the hazard coefficient.

Key words: ERA, Industrial emissions, Pollutant dispersion modelling.

INTRODUCTION

The WHO (2016) estimates that 72% of premature deaths related to outdoor air pollution are due to ischaemic heart disease and stroke. Also, 14% are due to chronic obstructive neuropathy or acute lower respiratory tract infection and another 14% to lung cancer.

Risk assessment is a tool that can be used to estimate and quantitatively rank the health impacts of exposure to an environmental pollutant on the population. In this way, decisions can be made that are supported by the available scientific information (Evans *et al*., 2003).

On the other hand, the ERA is an instrument of fundamental importance in the field of environment and health that is not yet part of the procedure applied by environmental agencies in the province of Entre Ríos. Therefore, this work is a relevant precedent in the field, where direct pollutant measurement tools are applied and reference factors accepted by international organisations are used.

METHODOLOGY

ERA is a scientific process applied to estimate the probability of adverse effects on human health due to exposure to hazardous substances (NJDEP, 2009). In this context, this work focuses on conducting an ERA for exposure to gaseous emissions associated with mobile sources, by people who perform aerobic physical activities in the city of Villa Elisa, Entre Ríos.

This study is carried out as a cross-sectional study, which took place during the summer season. Due to the changes in the habits of the inhabitants in the execution of outdoor physical activities, this cut is carried out in order to achieve a representative result of the real situation.

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Environmental risk assessment

The methodology used for this ERA is based on the framework of the phases established in 1986 by the United States Environmental Protection Agency (EPA). It has incorporated new tools over time. The phases included are i) hazard identification, ii) dose-response assessment, iii) exposure assessment and iv) risk characterization. These are preceded by a planning stage, focused on characterizing the basic aspects to be considered in the study.

Hazard identification

This phase focuses on identifying the types of adverse health effects that may be caused by exposure to the agent in question (EPA, 2021). This work aims to generate a risk assessment of exposure of citizens engaged in aerobic activities to emissions associated with vehicular sources in the main avenues of the city of Villa Elisa. Therefore, the identification of agents will be functional to this purpose.

Dose-response assessment

This step is a quantitative process to identify the relationship between the exposure dose to the hazard in question and the occurrence of adverse effects (EPA, 2021). In this step of the risk assessment, information was sought from the agents to be evaluated regarding the characteristics of the substance (carcinogenic or non-carcinogenic) and reference values, according to those characteristics according to the scientific literature.

Exposure assessment

It is the process of measuring or estimating the magnitude, frequency and duration of human exposure to an agent in the environment (EPA, 2021). The exposure assessment was determined from the direct measurement of the pollutants covered in this study. From these, it was decided to work with the average concentrations of pollutants, thus avoiding the maximum concentration values, which represent one-off events and are not representative of the real scenario. In order to carry out the estimation, it was decided to incorporate a control census to define the times of day that would represent the worst exposure scenario and then carry out the air quality measurements.

Sample census

In the first instance, the main sites of interest where the population engages in outdoor aerobic physical activity were evaluated. Once the areas were determined, a control census was carried out in order to identify the times of day when the greatest number of athletes and vehicle traffic (identified as the main source of atmospheric pollution) are registered. Then, once the witness census was carried out and the information was processed, it was possible to establish the time of day that represented the worst exposure scenario, represented by the highest number of vehicles circulating per minute.

Air quality measurements

Once the worst-case exposure scenario was determined, air quality measurements were carried out in the areas identified as usual for outdoor physical activities. For air quality monitoring, an 8-channel IAQ (Air Quality Monitor) YESAIR portable measuring equipment was used, which has three electrochemical sensors for SO2, NO2 and H2S detection and a pump with a PM2.5 sensor, with an updated calibration certificate. Measurements were made throughout each previously established zone individually, on alternate working days, during the months of January and February 2020, in a total of 18 surveys for each zone. For the monitoring, the equipment was programmed to automatically record concentrations every 10 seconds while each study zone was walked back and forth, estimating a measurement day of 1 hour and 15 minutes for the 4 zones.

Once the surveys were completed, the concentrations were processed using RStudio software. In this way, the measurement data were statistically evaluated for each zone as a whole. An analysis was carried out to determine the existence of significant differences in the level of pollutant concentration for the 4 study zones. For this purpose, a one-factor analysis of variance (ANOVA) was carried out, considering as dependent variables the average concentrations for each agent evaluated per survey day in each zone and as factor levels for each zone.

Risk characterization

Once the concentration of each pollutant had been determined, the risk characterization was carried out in accordance with the procedure established by the EPA.

This step was carried out by integrating toxicological information, exposure parameters and the concentration of pollutants to which the population is exposed. In this sense, the quantitative assessment of the non-carcinogenic risk of sulphur dioxide and particulate matter (equation 1) was carried out using the Hazard Quotient (HQ).

(1)

C= Concentration found (µg / m^3) and *RfC*= Reference concentration (µg / m^3)

RESULTS

Risk assessment is a scientific process used to estimate the probability of adverse health effects from human exposure to hazardous substances. (NJDEP, 2009)

As mentioned above, the procedure followed to perform a risk assessment consists of i) hazard identification, ii) dose-response assessment, iii) exposure assessment and finally iv) risk characterization.

These stages are preceded by the planning of the risk assessment. The main purpose of the risk assessment is to set out the general exposure scenario.

Description of the study area

The town of Villa Elisa is located in the center-east of the province of Entre Ríos, constituting one of the cities of the Department of Colón, according to information from the municipality of Villa Elisa (2020). This locality is characterized by the development of activities such as agriculture and livestock farming. Tourism and poultry farming are the main sources of economic resources for the city. Livestock farming is mainly oriented towards the production of meat and milk. Its exploitation is mainly extensive on natural pastures, occupying an important portion of the territory. Agricultural activity is based on the production of rice and soya, occupying the largest areas of the rural area of Villa Elisa and the area of influence. On a smaller scale, wheat, maize, sorghum and sunflower are grown.

Likewise, the tourist activity has generated a high impact on the local economy, starting with the opening of the hot springs complex at the end of 1999. It has experienced extensive growth, and it is estimated that it currently occupies a privileged place in the generation of financial income and employment. In addition to these, there are other outstanding activities, such as the production of poultry (chickens) for meat consumption, honey production, forestry, small and medium-sized industries.

According to data provided by the National Institute of Statistics and Census (INDEC), in 2010 the town of Villa Elisa had a population of 11,117 inhabitants in urban and rural areas, with an estimated surface area of 19,200 hectares in rural areas and 4,880 m2 in urban areas.

With regard to the climatic characteristics, the average annual temperature is 17º C, reaching maximums of up to 37º C in the summers (December to February) and minimums of up to approximately 2ºC in the winters (June to September). In terms of rainfall, the annual average is around 1,000 mm. (Municipalidad de Villa Elisa, 2020).

The locality of Villa Elisa is clearly sectored by its urban structure. In this sense, it has two wide avenues that make up the area of greatest activity. These avenues have central paths made of cobblestones and ceramic tiles, surrounded by large trees and flowerbeds with seasonal plants. Both avenues have an intersection between them. This point forms a roundabout where the Catholic church "Virgen Niña" is located at the intersection of both avenues (see figure 1). In this way, and according to the activities in each sector of the avenues, two residential areas can be established, a commercial area and, on the other hand, the main entrance to the city. In this way, the zones were defined according to table 1.

Table 1: Study areas

Zone	Characteristic
1	Mitre Avenue, democracy monument area (entrance to the city)
2	Avenida Urquiza school area (residential).
3	Avenida Mitre area of the municipal corralón (residential area)
4	Avenida Urquiza downtown area (commercial)

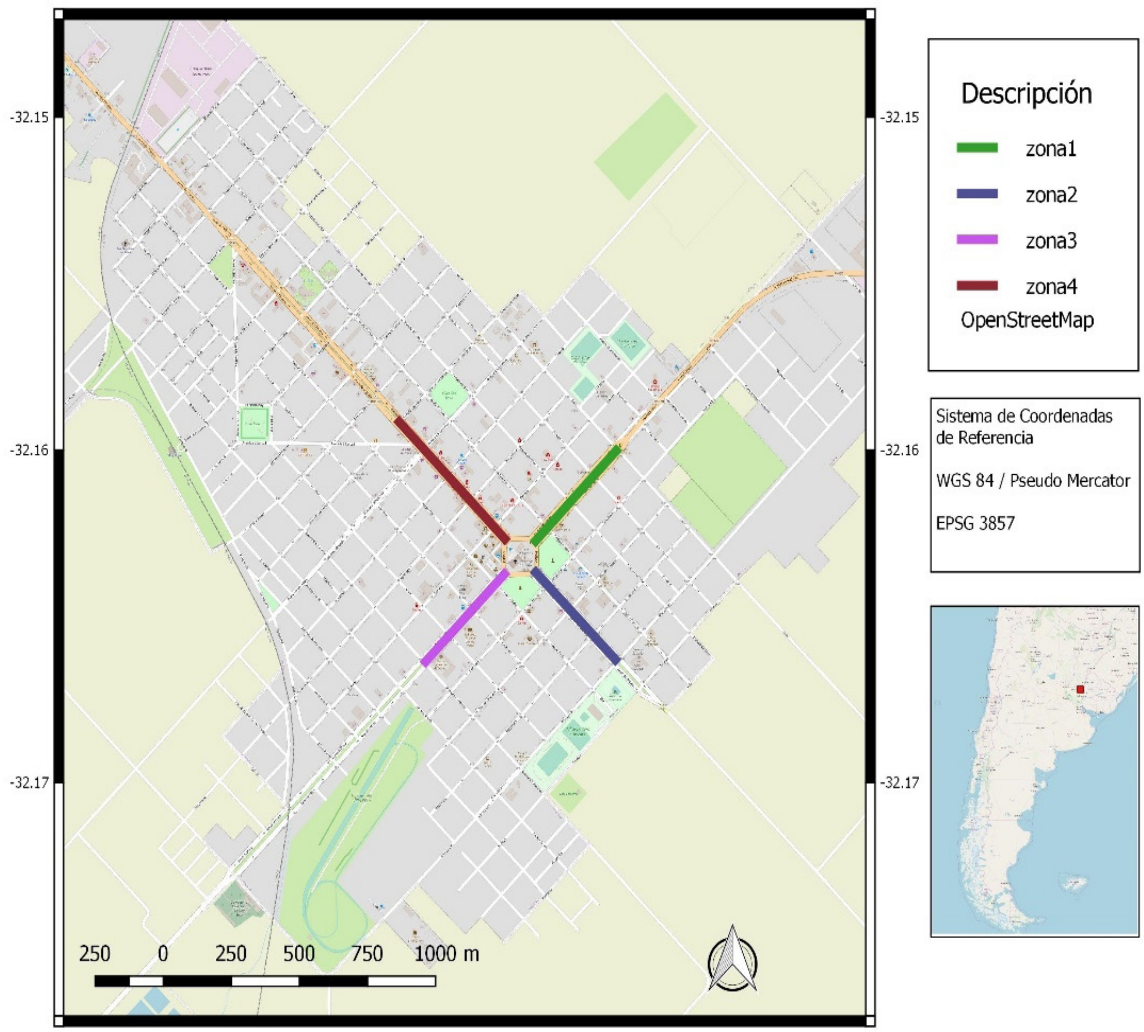

Figure 1 Study áreas

These avenues are one of the main places where people gather for outdoor aerobic activities (mainly walking). This activity, carried out at times of high traffic flow, generates an increase in exposure to vehicular emissions from the burning of fossil fuels.

Hazard identification

As described in the methodology, in this phase the substances considered in the ERA were identified. In this sense, taking into account the technical capabilities and the source of the substances, measurements of SO2, NO2 and PM2.5 were performed. The agents to be evaluated were selected based on the availability of air quality measurement sensors in portable equipment, focusing the study on the components linked to emissions generated by automobiles.

Dose-Response Assessment

In this step of the risk assessment, information was sought on the agents to be evaluated. This information collected the characteristics of the substance (carcinogenic or non-carcinogenic) and reference values, depending on these characteristics according to the reference scientific literature. Table 2 presents the summary data for each agent evaluated.

Table 2: Reference factors of the pollutants evaluated for air quality.

Agent	CAS	Classification	OMS	CALEPA-OEHHA (RAIS)	ATSDR (RAIS)	Ley 6.260 Dcto. N° 5837 MB-SCE
NO_2	10102-44-0	Non carcinogenic	40 µg/m3, annual average 200 µg/m3, average in 1 hour	RfC 4.70E-1 mg/m³ in 1 hour.		[1]0,4 mg/m3 (CASP[1]) [1]0,1 mg/m3 (ACLP [2])
SO_2	5/9/7446	Non carcinogenic	20 µg/m3, 24-hour average 500 µg/m3, 10-minute average	6.60E-1 mg/m³ average in 1 hour	RfC aguda: 2.62E-2 mg/m³	0,5 mg/m3 (CASP) 0,05 mg/m3 (ACLP)
PM2.5		Not classified (IARC)	10 µg/m3, annual average. 25 µg/m3, 24-hour average			

Concentration Allowable for Short Periods (CASP). (CAPC). [2] Admissible Concentration for Long Periods (ACLP)

Reference concentrations, reference doses, unit risk factors, among others, are developed based on toxicological studies. These studies are carried out by groups assigned to that purpose. This is done by different agencies, including the USEPA, through its Integrated Risk Information System (IRIS), the Office of Environmental Health Hazard Assessment (OEHHA), the Agency for Toxic Substances and Disease Registry (ATSDR) and the World Health Organization (WHO), among others. On the other hand, Law 6,260, Decree No. 5837 MBSCE, establishes the guideline levels for different measurement periods. This regulation is in force in the province of Entre Ríos and is taken as a reference in air quality.

According to the classification of these pollutants, the ERA will be performed as non-carcinogenic agents.

Exposure assessment

In this phase, exposure is assessed in order to identify the affected population and, if possible, to estimate the amount, frequency, time period and route of exposure. Exposure is understood as the contact between the human being and the environment with a specific contaminant during a given period of time.

In accordance with the proposed methodology, the execution of the field work (witness census and in situ measurements) was carried out during the same season of the year. This was done with the purpose of obtaining representative results, considering that the habits of the population can be modified in different seasons of the year. This would affect the dynamics of the activities. Following this criterion, the survey was conducted during the months of December 2019, January and February 2020.

Witness census

In the first instance, a control census was carried out in the study area. The objective was to gather information on the behavior of vehicular traffic in the four zones identified in the planning phase, which concentrate the local population for the development of aerobic activities. These activities are mainly walking, on paths located along the main avenues of the city. In this way, we sought to define the worst-case exposure scenario in order to perform air quality measurements.

The witness census was carried out during two consecutive weeks, on alternating working days during the first two weeks of December 2019, counting a total of 9 surveys for each zone. Vehicle and athlete activity was recorded by direct observation and counting of vehicles and athletes during alternating 1-minute periods, in a 10-minute day for each study zone. In turn, the survey was carried out at three times of the day as shown in Table 2.

From this census, the average number of vehicles per minute that transited in each zone during the survey time was determined. Thus, it was established at the time of day (B), between 18:30 and 19:30 hours, according to table 3 below.

Table 3: Average number of vehicles per minute by zone and time of survey.

	A	B	C
Zone1	9,95	6,95	12,65
Zone 2	7,95	5,7	13,55
Zone 3	8,05	7,7	10,8
Zone 4	10	9	14,45

Air quality measurement

It was carried out according to the methodology proposed in this work. In all cases, the measurement procedure was carried out by performing the following steps: turning on and activating the equipment, assigning folders to save the measured data, walking through the study areas holding the equipment at a height of 1.5 meters, downloading data to a PC, formatting the equipment's memory card.

Processing of surveyed data

Once the surveys had been carried out, we proceeded to process the concentration data to obtain descriptive statistics for each zone.

Tables 4 - 8 show the results for zones 1, 2, 3 and 4, respectively.

Table 4: Statistical summary of measurements made in zone 1

	Min.	Max.	Media	Variance	Standard deviation
NO_2 (mg/m^3)	0,000	0,188	0,00041	0,0007	0,009
SO_2 (mg/m^3)	0,000	2,096	0,638	0,250	0,500
PM2.5 (mg/m^3)	0,002	0,016	0,006	6,133	0,002

Table 5: Statistical summary of measurements made in zone 2.

	Min.	Max.	Media	Variance	Standard deviation
NO2 (mg/m^3)	N/D[1]	N/D[1]	N/D	N/D	N/D
SO2 (mg/m^3)	0,000	1,834	0,580	0,200	0,447
PM2.5 (mg/m^3)	0,001	0,039	0,006	0,011	0,003

Table 6: Statistical summary of measurements made in zone 3.

	Min.	Max.	Media	Variance	Standard deviation
NO_2 (mg/m^3)	0,000	0,188	0,001	0,0002	0,014
SO_2 (mg/m^3)	0,000	1,834	0,530	0,182	0,427
PM2.5 (mg/m^3)	0,002	0,016	0,006	0,008	0,003

Table 7: Statistical summary of measurements made in zone 4.

	Min.	Max.	Media	Variance	Standard deviation
NO_2 (mg/m^3)	0,000	0,565	0,001	0,001	0,024
SO_2 (mg/m^3)	0,000	2,096	0,637	0,232	0,481
PM2.5 (mg/m^3)	0,001	0,048	0,007	0,0031	0,005

[1] Value not detected by the equipment.

Analysis of differences in concentrations between study zones

An analysis was performed to determine the existence of significant differences in the level of contaminant concentration for the 4 study zones. For this purpose, a one-factor analysis of variance (ANOVA) was performed considering as dependent variables the average concentrations for each agent evaluated per day of survey in each zone and as factor levels for each zone.

Given the characteristics of the data collected, the one-factor ANOVA was run for SO2 and PM2.5. This is because for NO2, too many values are below the detection limit of the equipment. Therefore, this pollutant is excluded from the analysis of variance after failing the assumption tests.

Since the P-value is higher than 0.05 for both pollutants (SO2 = 0.9583 and PM2.5=0.6035), it is considered that there is no statistically significant difference between the pollutant mean between one zone level and the other, with a 95.0% confidence level.

Once the data have been analyzed in the exposure assessment stage, in addition to determining by direct or indirect measurement (using emission factors and dispersion modeling) the concentration of contaminants, the exposure dose can be determined (equation 1). However, considering that no inhalation reference dose is available for the agents evaluated (Table 1), the dose estimation will not be performed.

Risk characterization

Risk characterization is the final step in ERA. The objective of this phase was to perform a quantitative estimation of the risk to human health, based on the previous steps. As defined in Table 2, the agents evaluated in this work are classified as non-carcinogenic. Therefore, the quantification will be performed according to this scenario.

The process was carried out considering the reference factors for each substance. In this sense and according to the summary of information presented in Table 2, the characterization is performed according to acute exposure periods given the characteristics of the monitoring performed for concentration measurement. In this way, the average concentrations of pollutants are considered, thus avoiding working with the maximum concentration values. The latter represent punctual and non-representative events.

In this sense, by applying equation 1 corresponding to the characterization of the risk of inhalation of non-carcinogenic substances for short periods, the hazard coefficient (HQ) was obtained.

Thus, the HQ results (Tables 9 to 12) are summarized for each evaluated zone.

Table 9: Hazard coefficient zone 1.

	Concentration (mg/m^3)	**RfC (mg/m^3)**	**HQ**
NO_2	0,0004	0,470	0,0008
SO_2	0,638	0,660	0,967
PM 2,5	0,006	0.025	0,240

Table 10: Hazard coefficient zone 2.

	Concentration (mg/m^3)	**RfC (mg/m^3)**	**HQ**
SO_2	0,580	0,660	0,879
PM 2,5	0,006	0.025	0,240

In the case of zone 2, the determination of the hazard coefficient for exposure to NO2 was not performed since, for this zone, the measuring equipment does not detect concentrations of this agent.

Table 11: Hazard coefficient zone 3.

	Concentration (mg/m^3)	**RfC (mg/m^3)**	**HQ**
NO_2	0,001	0,470	0,002
SO_2	0,530	0,660	0,803
PM 2,5	0,006	0.025	0,240

Table 12: Hazard coefficient zone 4.

	Concentración (mg/m³)	RfC (mg/m³)	HQ
NO_2	0,001	0,470	0,002
SO_2	0,637	0,660	0,965
PM 2,5	0,007	0.025	0,280

From these results, the hazard quotient (HQ) could be defined. According to Mokhtar et. al, (2014), the resulting value is less than one (HQ <1). This indicates that the pollutant concentration is below the reference concentration value (RfC). However, it should be noted that HQ< 1 does not suggest the non-existence of adverse effects, but rather indicates that there is an acceptable potential risk to agent exposure for the case evaluated.

CONCLUSIONS

In this study, the impact on the health of the population that periodically frequents the main avenues for outdoor aerobic activities (walking) was evaluated. In this sense, exposure to agents related to vehicular emissions from fossil fuel burning was evaluated.

According to the results of this ERA, the hazard coefficient has not exceeded the value of 1. Therefore, the hazard due to inhalation exposure during the hours that represent the worst exposure scenario does not present a potential extra risk to the effects of the evaluated pollutants. It should also be noted that values close to 1 have been observed for SO2 in the study zones corresponding to the main entrance to the city (zone 1) and downtown (zone 4). On the other hand, it is necessary to consider that the risk characterization was carried out by applying average concentrations, observing eventual and non-representative maximum concentrations that exceed the maximum concentration levels established by the WHO for short periods for PM2.5 exposure in zones 2 and 4.

On the other hand, it was determined that there are no significant differences between the study areas for SO2 and PM2.5 concentrations. Therefore, it is not possible to determine an area with a higher level of risk.

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