CONCENTRATION AND DISTRIBUTION OF HEAVY METALS IN ASH
EMITTED BY THE SUGAR FACTORY LA GLORIA, VERACRUZ, MEXICO

SHORT TITLE: HEAVY METALS IN ASH

DISTRIBUCIÓN Y CONCENTRACIÓN DE METALES PESADOS EN CENIZA
EMITIDA POR EL INGENIO LA GLORIA, VERACRUZ, MÉXICO

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RESUMEN

Las actividades agrícolas son una de las fuentes principales de contaminación. Una de ellas es la quema de la caña de azúcar y el proceso agroindustrial que se lleva a cabo en los ingenios que emiten un gran volumen de partículas que contienen metales pesados, tales como el cadmio (Cd), cobre (Cu), plomo (Pb) y zinc (Zn). Estos metales causan daño y
serios problemas de contaminación a la salud pública. Por lo tanto, el objetivo de este estudio fue determinar las concentraciones y la distribución espacial de Cd, Cu, Pb y Zn presentes en las partículas emitidas por el ingenio La Gloria y por la quema de la caña de azúcar en los agroecosistemas regionales, en función de la distancia a la cual tal material se depositó durante el proceso de emisión. La investigación se llevó a cabo en la comunidad La Gloria, Veracruz, donde se ubica el referido ingenio. Se consideraron dos áreas de estudio: la primera fue la Zona A, localizada a una distancia de 50 a 400 m del ingenio y la segunda, la Zona B, ubicada a distancias de 401 a 900 m de éste. Un total de 51 sitios de muestreo de ceniza se seleccionaron al azar, 17 en la Zona A y 34 en la Zona B. Las muestras recolectadas dentro de dicha comunidad fueron representativas del área considerada como de mayor incidencia de material particulado. Un análisis de medias mostró que las concentraciones de Cd, Cu y Pb resultaron mayores en la Zona A que en la Zona B (100.6179 > 66.3614 µg/g; 92.2825 > 47.2526 µg/g; 876 8559 > 701.3888 µg/g). Sin embargo, la concentración de Zn en Zona B fue mayor que en la A (28.5941 > 28.8798 µg/g). En cuanto a la distancia, no se encontraron diferencias estadísticas significativas entre zonas.

Palabras clave: contaminación del aire, material particulado, caña de azúcar.

**ABSTRACT**

Agricultural activities are one of the main sources of environmental pollution. One such source is sugarcane burning and the related agroindustrial processes carried out by sugar mills that emit a great volume of particulate matter containing heavy metals such as cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn). These heavy metals result in serious
pollution problems and harm to public health. Therefore, the aim of this study was to
determine the concentrations and spatial distribution of the heavy metals Cd, Cu, Pb and Zn
present in the particulate matter emitted by La Gloria sugar mill and by sugarcane burning
in regional agroecosystems, as a function of the distance at which such material was
deposited during the emission process. The research was carried out in the town of La
Gloria, Veracruz where the sugar mill is located. Two study areas were established: the
first, Zone A, was located 50 to 400 m away from the mill, and the second, Zone B, 401 to
900 m away. A total of 51 ash sampling sites were randomly selected, 17 in Zone A and 34
in Zone B. The samples collected within the town were representative of the area with the
highest incidence of particulate matter. An analysis of means showed that the
concentrations of Cd, Cu and Pb were higher in Zone A than B (100.6179 > 66.3614 µg/g;
92.2825 > 47.2526 µg/g; 876 8559 > 701.3888 µg/g). However, in Zone B the
concentration of Zn was higher than that in A (28.5941 > 28.8798 µg/g). As regards to
distance, no significant statistical difference between zones was found.

Key words: air pollution, particulate matter, sugarcane.

INTRODUCTION

The agroindustry’s concern must be the conservation and transformation of raw materials,
as well as to extract, enrich and concentrate the components that give value to them;
agroindustrial activity is closely related to urban development and the environment.
Basanta (2007) pointed out that at global level, the environmental issues of the greatest
concern like the degradation and alteration of the environment by agroindustrial residues
such as liquids and solids, which contribute to water pollution both in surface and ground water, are of public concern.

In this sense, agriculture is intricately enmeshed in the environmental issue due to the processes required for transforming raw material. Among them, sugar mills emit ash into the atmosphere consisting of a high volume of particulate matter together with a high concentration of heavy metals such as cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn). High concentrations of heavy metals converge in exposed areas, such as: dwellings, material goods and, especially, agroecosystems. In addition, nearby areas become very vulnerable to these concentrations because of their non-biodegradable nature and, in addition, the negative effects they exert on different crops and their bioavailability may be hazardous to environmental and human health (Prieto et al. 2009).

The sugarcane industry is of great importance from the social, cultural, political and economic viewpoints, since it is a very important source of jobs. This agroindustry generates around two million jobs indirectly and directly, with prevalence in most tropical and subtropical areas (SE 2012). This leads to severe pollution problems due to the increase in the volume of industrial, agricultural and domestic particulate matter produced by the sugarcane activity, which adversely affects the health of the environment (Basant et al. 2007).

Determining the concentration of heavy metals present in the volatile particles emitted by the La Gloria mill not only serves to assess their toxicological potential and implications for the environment, but also contributes to the development of strategies to reduce and mitigate environmental pollution (Rovira et al. 2010). Therefore, the aim of this research was to determine the concentrations and spatial distribution of the heavy metals Cd, Cu, Pb and Zn present in the particulate matter emitted by the La Gloria sugar mill and sugarcane...
burning in regional agroecosystems, as a function of the distance at which such material was deposited during the emission process.

MATERIALS AND METHODS

Selection of the study area

This study was carried out from December 2015 to April 2016 in the supply and housing areas of the La Gloria mill, Veracruz. These areas are geographically located between 19° 29' and 19° 23' NL and between 96° 21' and 96° 31' WL in the central coastal plain region of the state of Veracruz, Mexico were the average wind speed in the area is 43 km/h.

In the studied area there are some rural communities close to La Gloria mill along with the rural community called La Gloria, which is practically adjacent to it.

The predominant climate is Aw1, being warm subhumid with a mean annual temperature greater than 22 ºC and a coldest month temperature greater than 18 ºC. The precipitation of the driest month is less than 60 mm; the summer rainfall occurs with precipitation/temperature index between 43.2 and 55.3; the annual precipitation is around 1400 mm according to Köppen climate classification (García 2004). There are three seasons throughout the year that are clearly distinguish, i.e., drought, rainy and strong northerly winds.

Collection of particulate matter samples

This activity was carried out after and during the sugarcane harvesting, because in this time the sugarcane mill was operating day and night. This gave rise to the particulate matter
(ashes) emission from La Gloria mill. Once this process was completely established, sometime after it the sample collection started in each selected site.

Two studied areas, Zone A and Zone B, were selected for the collection of the particulate matter samples, having a total amount, for both zones, of 51 sampling sites; with Zone A being the closest to the La Gloria mill (Fig. 1). During the operation of La Gloria mill, a number of 50 samples were collected for each site; each sample consisted of 20 g/d. After each sampling, all the particulate matter samples were taken to the lab until the 50 sampling was completed for every site of zones A and B considered in this study. After this, all the particulate matter accumulated during the 50 sampling in each site was carefully mixed up, from which a composed sample of 500 g was obtained and then sieved with 250 µm No. 60 mesh for the removal of undesirable material. The resulted samples were taken to the lab for further analyses. The recollection of particulate matter samples in all the 51 sampling sites of zones A and B was done in relatively small cylindrical containers with the following dimensions: a base with a 40 cm diameter and a 15 cm height. These sampling containers were placed at 30 cm above soil surface so as to reduce, as much is possible, the entrance of any other particles that could contaminate the particulate matter samples that were gradually entering into the referred containers. From each sieved sample, a weight of 50 g was taken and packaged in a previously labeled 16.5 x 14.9 cm ziploc bag. These bags were stored in closed desiccators to avoid moisture absorption from the environment and remained in them until their analysis in the laboratory (Fig. 2). These analyses were performed using the atomic absorption spectrophotometry technique.
**Figure 1.** Distribution and location of zones A and B where the ash collection sites were distributed in the study area (This figure was elaborated by the authors with the aid of the information provided by Google Earth).

**Figure 2.** Processes of: 1) collection, 2) sieving, 3) weighing, and 4) packaging of ash samples at the 51 selected sites.

**Samples homogenization**

Each sieved and homogenized sample of a weight of 50 g was taken and deposited in a one-liter cone of Imhoff, which contained 500 mL of distilled water. Then it was stirred up using a glass rod and let it rest for a minute. The fine particles that were not ashes precipitated at the bottom of the cone, while the ashes floated and were decanted at that moment on a long neck glass funnel, upon which a filter paper was placed so as to retain the ashes. Subsequently, the ashes were placed in a porcelain capsule to be dried up in an oven at 100 °C until a constant weight was reached. The dry ash sample was prepared to carry out its digestion in the CEM trademark microwave oven.

**Chemical analysis of particulate matter samples**

To carry out the lab analyses a Thermo Scientific iCE 3500 AAS System atomic absorption spectrophotometer was used, which is installed and operated in the lab of the Technological Institute of Boca del Rio, Veracruz. The analysis technique applied to the ash samples is described as follows:

1. Preparation of laboratory material for analysis of the particulate matter (ash) samples.

The preparation of the material used in the laboratory was carried out under the...
specifications established by NOM-117-SSA1-1994 and NOM-242-SSA1-2009 for the analysis of heavy metals, in which the various analyses methods for determining Cd, Pb, Cu, and Zn in food, drinking water, purified water and specific substrates by atomic absorption spectrometry are described.

2. Cleaning of teflon and glass material for sample analysis. The cleaning of the teflon material for digestion and glassware was carried out with phosphate-free mild (neutral pH) soap at 10 % per liter of distilled water. This soap was used in order to avoid ionic interferences in the spectrophotometer reading. After soaping the material and rinsing it with tap water, it was immersed in a distilled water solution with 20 % nitric acid (HNO₃) (per liter).

The material, such as teflon beakers, remained for 1 to 2 hours in this solution, while the glassware remained for 24 hours. Once the process of removing any metal residue in the HNO₃ solution was completed, the material was immersed in type II or double-distilled water; the glassware and teflon beakers remained there for up to 24 hours to ensure a complete removal of the acid.

Finally, the material was removed from the type II water and drained onto the absorbent material. The clean and dry material was suitably placed in duly-labeled, airtight (ziploc) bags or containers with a lid.

3. Digestion of particulate matter samples. First, 0.5 g of particulate matter sample were weighed; each sample was then deposited in an HP-500 teflon beaker, to which 10 mL of 70 % (suprapur) reactive grade HNO₃ were added. Previously, a safety membrane was placed inside each valve or blue plug. The valve was placed in the beaker cup and gently adjusted to the bottom. They were then placed in a CEM MARS X microwave oven.
All samples were analyzed with a blank sample containing 0.5 mL of double-distilled water and 10 mL of HNO₃ of the same characteristics, as well as a reference control. Programming of the digestion process was by the Soil-3051 HP500 method. The power was adjusted based on the number of beakers used: 1-3 (300 w), 4-6 (600 w) and 6-12 (1200 w) (Table I).

Once the digestion was completed, the Teflon beakers were removed from the oven and placed in the fume hood for toxic vapors, using the required safety measures, such as the use of glasses, a mask and gloves, in order to facilitate the handling of the samples. The blue valve on the beakers was carefully opened to gradually lower the pressure. Subsequently, the beakers were carefully opened to prevent the pressure change from ejecting the sample outside of them.

The samples obtained were filtered using a Nalgene bottle with a 0.45 µm millipore filter and a vacuum pump. The filtrate was poured into a 25 mL volumetric flask and brought to volumetric level with type II or double-distilled water. The filled flasks were stirred to homogenize the sample, which was then poured into a previously-labeled glass or plastic amber container. Finally, parafilm was placed in the mouth of the amber containers, which were then placed in airtight (ziploc) bags for storage at about 4 °C until read on the atomic absorption spectrophotometer.

Prior to the sample reading by using the mention spectrophotometer, a calibration curve had to be prepared for each metal analyzed herein for which certified standards of trademark High Purity Stand Ards were used. Thus, the sample readings and standards are described for each metal as follows: for Cd a wavelength of 228.8 nm with a 50 % current lamp, a flame of air-C₂H₂, with a lighter height of 4.1 mm and a combustion flow of 1.0 L/min were used. As regard to Cu a wavelength of 324.8 nm with a 75 % current lamp, a flame of
air-C2H2, with a lighter height of 4.1 mm and a combustion flow of 1.0 L/min were used. With reference to Zn, a wavelength of 213.9 nm with a 75 % current lamp, a flame of air-C2H2, with a lighter height of 7.0 mm and a combustion flow of 1.0 L/min were used. Finally, concerning Pb a wavelength of 217.0 nm with a 90 % current lamp, a flame of air-C2H2, with a lighter height of 5.4 mm and a combustion flow of 1.3 L/min were used. In addition, the optimization of instrumental specifications such as airflow, acetylene gas, lamp wavelength and lighter height for each metal was done. After this, the equipment became stable and then the corresponding standards, with known concentrations, and with a range from lower to higher concentration of analyte, were read for each studied metal. To obtain a calibration curve with a correlation coefficient greater than 0.99, the reading of the absorbance of the digested samples was made. Hence, the obtained results remained within the concentrations of the calibration curve.

RESULTS AND DISCUSSION

Concentration of heavy metals in particulate matter

Cadmium (Cd)

It was found that the concentrations of Cd in the analyzed samples ranged from 0.451 to 432.81 µg/g for both zones where samples were collected (Fig. 3). In Zone A, the highest Cd concentrations were recorded.

Figure 3. Distribution of Cd concentrations at the 51 sampling points.
It was also found that Cd exceeded the maximum allowable limit for industrial use according to the Official Mexican Standard (NOM-147-SEMARNAT/SSA1-2014), which is 39 µg/g. The obtained concentrations of Cd also exceeded the concentration of 6 µg/g established by the Federal Commission for Protection from Health Risks (COFEPRIS for its initials in Spanish) for bivalve mollusks as the allowable limit for consumption and is considered to pose a risk to public health when the particulate matter containing Cd is deposited in water streams or water bodies (Lango-Reynoso et al. 2010). It is important to emphasize that these concentrations were only found in 50 g of particulate matter.

Likewise, heavy metals have been found in different concentrations in fish, meat and milk resulting from bioaccumulation and transport processes from the environment to water sources. Some species such as oysters, shellfish and mollusks accumulate the Cd from water in the form of linker peptides until reaching concentrations between 100 and 1,000 µg/g (Luo et al. 2009). Reyes et al. (2016) mentioned that Cd concentration values higher than 50 µg/g in industrial activities represent a risk to public health, if inhaled by workers exposed to such concentrations.

As a result of population growth, human beings have been the ones most affected by industrial development. In this regard, several studies have detected that the organ most susceptible to potential damage caused by Cd inhalation is the lung. Chronic obstructive airway diseases associated with prolonged exposure to intense Cd inhalation have also been reported. Among other conditions, lung cancer development has also been documented (Gomez-Caminero et al. 2001).

**Copper (Cu)**
Figure 4 shows that the Cu concentration values ranged from 0.034 to 356.91 µg/g. The sampling points closest to the emission source had the highest concentrations of this metal. In addition to the mention before, Mohanraj et al. (2004) reported that heavy metals in airborne particulate matter, such as Cu, it can be also attributed in part to the vehicular emissions. This finding can be supported from the fact that there was a permanent transit, day and night, of 530 big lorries transporting the harvested sugarcane from the fields to the sugar mill. Moreover, it was also observed the transit of public transportation and vehicles belonging to the people living in the rural areas where this study was carried out.

Kabata-Pendias (2000) reported a Cu concentration of 0.2 µg/g in agricultural soils in the Aconcagua River basin (Valparaiso Region, Chile). This causes the plants to show susceptibility to the Cu concentration in these soils due to its phytotoxic effects.

The arrival of Cu to water bodies and, subsequently, to underground streams is the result of agricultural and industrial activities that emit this element in the form of particulate matter (Herrera-Núñez et al. 2013). The average Cu concentration found in the waters of the Chico River, Venezuela, was 11.52 µg/g; this concentration was similar to the maximum value established for non-polluted environments. It was also reported for the Boca River in Paparo, Venezuela, that the Cu level was higher than 46.1 µg/g because it is located in an area that is polluted by industrial activities (Sadiq 1992, Acosta et al. 2002).

In this sense, the Cu concentration found for a 50 g sample in this study area could imply a harm to either human health or the environment. However, there is a potential future risk, due to the adhesion of this heavy metal to human, animal and plant tissue.

The exposition of Cu and other heavy metals adhered to the particulate matter and released to the atmosphere as a result of the sugarcane burning and the agroindustrial activity of the La Gloria mill cause a high risk and harm to the human health. According to the latter, the
NOM-010-STPS-1999 presents the maximum permissible limits for Cu smoke exposition during 8 daily hours or 40 weekly hours. The value for a maximum permissible exposure limit (PEL) is 0.2 µg/m and the value for a short term exposure limit (STEL) is 2 µg/m.

Since the devices used herein had a total volume of 0.018 m$^3$ in which a weight of about 20 g of particulate matter was collected in each sampling for each site, then when projecting the container volume to a cubic meter, the amount of ashes as well as smoke in the latter is about 1 061 g. Therefore, the obtained results may be clearly suggesting that the majority of the concentrations of Cu obtained in this study is greater than the permissible limit established by the NOM-010-STPS-1999 (Fig. 4). The reason for writing down the former paragraph in such way is because the particulate matter sample was not directly taken in a cubic meter as mentioned by the referred NOM.

**Figure 4.** Distribution of Cu concentrations at the 51 sampling points.

**Lead (Pb)**

The Pb results obtained herein showed an upward behavior in its concentrations, which were observed in a range from 101.45 to 1892.1 µg/g (Fig. 5).

**Figure 5.** Distribution of Pb concentrations at the 51 sampling points.

NOM-147-SEMARNAT/SSA1-2014 set a maximum permissible limit of 600 µg/g for the concentration of Pb in industrial zones. The results observed in the studied area surrounding La Gloria mill, it was observed that the concentration levels are higher than those established by this standard. This indicates that the environment is being affected by the Pb.
concentrations present in the particulate matter emitted by this mill and by sugarcane burning.

The Pb that is dispersed into the atmosphere, which adheres to the particulate matter that results from industrial and agroindustrial product processes, is responsible for causing harmful health effects to people, animals and plants (Sánchez 2000). It has been reported that some plant species have a tolerance level of less than 1 µg/g of Pb bioaccumulation in the soil. When this Pb concentration is exceeded, plant organs do not assimilate this metal and therefore plants die. In addition, the Joint FAO/WHO Expert Committee on Food Additives and Codex Alimentarius (JECFA) established the maximum permissible limit of Pb in horticultural plants in the range of 100 to 300 µg/g (CAC 2011).

The maximum permissible limits set out in these standards are used as a reference for establishing safety criteria for agricultural products projected for human consumption. In this sense, the Pb concentrations found within the study area were higher than those indicated in these standards. Therefore, horticultural plants that are planted inside or close to the study area are exposed to contamination by Pb adhering to the particulate matter.

Zinc (Zn)

This element had the lowest concentrations with respect to the other heavy metals determined in the studied area. These concentrations were found in the range of 6.83 to 56.39 µg/g (Fig. 6). The NOM-127-SSA1-1994 and the Ecological Criteria for Water Quality (CE-CCA-001/89), both establish a maximum permissible limit of 5 mg/L, which is approximately equal to 5 µg/g. When this particulate matter is deposited in any water body that eventually can be used for human consumption such situation becomes a risk to public health.
Figure 6. Distribution of Zn concentrations at the 51 sampling points.

In this regard, Machado et al. (2008) reported concentrations of 7.41 µg/g in particulate matter within an industrial area of the city of Buenos Aires, Argentina, where there was also high diesel-powered vehicular traffic.

Even though the Zn concentrations observed in this study were lower than those found for Cd, Cu and Pb. This does not ensure that the agroecosystems are not at risk, since prolonged exposure to this metal may cause alterations or decreases in agricultural production (Risser and Baker 1990).

Tembo et al. (2006) also reported that the concentration of this element decreases in soil, plants and water bodies, due to factors such as temperature, rainfall and soil moisture, as well as to leaching and dispersion processes of this element by air. This latter process is also a function of the distance from the sampling sites to the emission source.

The concentration values of Cd, Cu, Pb and Zn found in the particulate matter samples, collected in sampling areas A and B of the studied area, do not show significant statistical differences. This could be partly attributable to the fact that a single mill with an emission source of considerable importance was considered. However, in this analysis it was found that Pb had a higher concentration in comparison to the other heavy metals identified in this research work.

Distribution and levels of contamination by heavy metals

A heavy metals index was constructed through a principal component analysis (PCA) for the concentrations of particulate matter collected at the sampling points under study. By
means of this analysis, the eigenvalues for each component were identified, with the explained variance and the amount of information that each component has also being observed. Subsequently, component one (C1) was chosen because of its greater explained variance (Table II).

According to the PCA this indicates that the first component (factor) has the highest eigenvalue of the factors, differentiating the highest and lowest value of the components. The PCA allowed also obtaining the factorial loads (index) of each variable, in which the sites with the highest and lowest concentration of the heavy metals were detected (Fig. 7).

**Figure 7.** Classification of contamination levels in high, medium and low groups, according to the Index obtained from the principal component analysis.

In this sense, it is convenient to remark that the source of energy to operate La Gloria mill is the fuel oil combined with bagasse of cane resulting in emissions of a great deal of particulate matter having elements (i.e. Pb and Zn) that are released by the fuel oil during its combustion. Such situation, in the opinion of the authors, results in the adherence of Pb and Zn during this process. In addition to the formerly mentioned, it has been reported that the heavy metals concentration, i.e. Zn, in the environment is increasing due to anthropogenic activities. A considerable amount of Zn is added as a result of industrial and mining activities as well as by the carbon combustion (Pacyna 1996, Shallari et al. 1998, He et al. 2005, Arruti et al. 2010). Therefore, when one can see the results derived from the principal component analysis, it is observed that Pb and Zn show a good correlation with factor 1. Therefore, it is reasonable to asseverate that the source of major impact in the Pb and Zn concentration is the fuel oil and bagasse combustion, which is enhanced by the
sugarcane burning and the permanent transit of lorries transporting the harvested sugarcane and the vehicles that belong to the people living in the rural areas involved in this study.

Furthermore, the PCA was a useful statistical tool to bring together the concentrations of the analyzed heavy metals into the following categories: high, medium and low. It made also possible to build up a map that included isolines for Cd, Cu, Pb and Zn.

Table III shows that factor one has a high correlation with Pb and Zn, which makes them the most representative.

**Distribution of particulate matter**

The particulate matter is emitted through the industrial chimney stack. The higher the chimney is, the greater the probability that the pollutants will be dispersed and diluted before affecting neighboring populations. The chimney’s visible emission is called a plume, and its height is determined by the speed and thrust of the gases coming out of the chimney (Lou et al. 2009). According to the distance at which the highest concentrations of particulate matter occur is not dependent on wind speed (Solís y López 2003); its highest concentration is maintained at a distance of 500 m from the emitting source. Usually the wind favors the dispersion of the pollutants and humidity plays a negative role in their dispersion, due to the concentration of smoke and particulate matter.

The distribution of the particulate matter in the surrounding area of La Gloria sugar mill and the sugarcane burning area presents a high level of concentration in the places closest to the emission source, with the distant sites being the ones that present medium and low concentrations. This is attributable to the dispersion, i.e. the transport of the particulate matter in the air, which depends on the prevailing weather conditions such as wind speed and direction that were observed while collecting the particulate matter samples. This
information was not available for the studied zone and it was not possible to get it from institutions like the Water National Commission (CONAGUA, by its initials in Spanish), that is why such information was not included in the article. The different types of volatile particle dispersion phenomenon caused accumulation in areas close to the source of emission and their transport to areas less far away.

It is necessary to make clear that the scope of this study was constrained to the determination of concentrations and spatial distribution of heavy metals like Cd, Cu, Pb and Zn present in the particulate matter emitted by the La Gloria sugar mill and sugarcane burning in regional agroecosystems, as a function of the distance at which such material was deposited during the emission process. The reason to stress this issue is due to the lack of financial support, which hinders the extension of this research work to other aspects.

Figure 8 shows the location of the sampling sites; the high, medium and low concentration levels are indicated by using the following geometric figures, i.e., circle, square and triangle.

Figure 8. Geographic distribution of sampling sites and concentration levels of the metals found in this study.

By means of an analysis of variance of the high, medium and low concentration types, it was found that there were significant statistical differences (p = 0.0001; Fig. 9).

Figure 9. Pollutant concentration level by types.

CONCLUSIONS
Each of the metals had different concentrations. The Cd exceeded the maximum allowable levels established by the standard NOM-147-SEMARNAT/SSA1-2014, in terms of heavy metal concentrations in industrial zones. This standard also establishes the maximum allowable limits for Pb; this metal exceeded, in this study, the maximum permissible limit established by this standard. Both Cu and Zn had low concentrations. However, their minimal presence does not make them any less dangerous for regional agroecosystems.

The particulate matter emitted by La Gloria mill shows high concentrations of the studied heavy metals, which affect, as mentioned in previous paragraphs, the flora, fauna and water of the region’s agroecosystems, due to the fact that the plants undergo modifications in their stomata opening, photosynthesis and transpiration, and their ability to synthesize chlorophyll is inhibited. Moreover, these concentrations degrade the soil and change its alkalinity.

Carrying out this research project posed a great challenge due to the presence of strong northerly winds, which greatly hampered the collection of ash samples in the studied sites. This leaves us with the task of developing appropriate equipment and instruments to carry out the monitoring of concentrations of heavy metals and other elements in the particulate matter emitted by La Gloria mill and sugarcane burning. Heavy metals such as Cd and Pb are considered carcinogenic to humans and represent a latent risk of bronco-respiratory and ocular diseases to residents living in the area where this study was carried out.

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REFERENCES


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TABLE I. PROGRAMMING OF THE MICROWAVE OVEN: SOIL-3051 HP500 METHOD FOR SOLID WASTE.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Power</th>
<th>Ramp</th>
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<td>1200 W</td>
<td>100</td>
<td>10:00 min</td>
<td>300</td>
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</tbody>
</table>

Note: The power was adjusted based on the number of beakers used: 1-3 (300 W), 4-6 (600 W) and 6-12 (1200 W). PSI = pressure per square inch, Ramp = the digestion time in each stage.

TABLE II. ANALYSIS OF THE EXPLAINED VARIANCE MATRIX.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
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<td>-0.912</td>
<td>-0.108</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.815</td>
<td>0.209</td>
<td>-0.190</td>
<td>0.506</td>
</tr>
<tr>
<td>Exploratory variable</td>
<td>1.345</td>
<td>1.058</td>
<td>0.999</td>
<td>0.597</td>
</tr>
<tr>
<td>Total proportion</td>
<td>0.336</td>
<td>0.265</td>
<td>0.249</td>
<td>0.149</td>
</tr>
</tbody>
</table>
TABLE III. ANALYSIS OF CORRELATION OF VARIABLES WITH COMPONENTS.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Eigenvalue</th>
<th>Total variance</th>
<th>Total cumulative value</th>
<th>Cumulative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.345</td>
<td>33.627</td>
<td>1.345</td>
<td>33.627</td>
</tr>
<tr>
<td>2</td>
<td>1.058</td>
<td>26.462</td>
<td>2.403</td>
<td>60.089</td>
</tr>
<tr>
<td>3</td>
<td>0.999</td>
<td>24.979</td>
<td>3.402</td>
<td>85.069</td>
</tr>
<tr>
<td>4</td>
<td>0.597</td>
<td>14.930</td>
<td>4.000</td>
<td>100.000</td>
</tr>
</tbody>
</table>