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RESEARCH ARTICLE

# Heavy metals and pesticide exposure from agricultural activities and former agrochemical factory in a Salvadoran rural community

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**Abstract** Pesticide handling in farming activities involves substantial hazards for the rural population and for the environment. In Latin America, it is estimated that the population at risk of being affected by heavy metals is over 4 million. This research describes the different types of exposure to pesticides and heavy metals in a rural population (Loma del Gallo), considering both environmental and occupational exposure. This study consists of an inspection in a former pesticide factory (QUIMAGRO), analysis of heavy metals in samples from surface and ground water in the community close to the factory, and a survey to the local population about their perceptions of pesticide exposures. Containers with 34.6 tons of chemicals improperly stored were identified in the former factory and removed by the government. Arsenic and cadmium were found in groundwater, and the highest values were 0.012 and 0.004 mg/l, respectively. These contaminants were also detected in most surface water samples, with maximum values of 0.026 and 0.0001 mg/l, respectively. Results of the survey show that of the 44 participants 42 % were farmers. Farmers used 19 different pesticide products containing 11 active ingredients. The most used active ingredients were paraquat (65 %), methamidophos (35 %), and atrazina

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(29 %). Eighty-two percent of the farmers did not use personal protective equipment. In addition to the pesticides used in the agriculture of the area, pesticide containers were removed from the QUIMAGRO area, but the pollution was still present at time of sampling and it is evident by the odor of the site. Surface water had the major concentration of heavy metals than the groundwater. Loma del Gallo population has been exposed to toxic pesticide from QUIMAGRO and agriculture for many years. The farmers carry out mishandling of pesticides and they not use PPE.

**Keywords** Heavy metals · Arsenic · Cadmium · Pesticide exposure · Pesticide management · Obsolete pesticides · Former pesticide factory · Central America · El Salvador

## Background

Exposure to pesticides and heavy metals is a serious threat worldwide to both humans and the environment. World Health Organization (WHO) estimates that three million acute pesticide poisoning occur around the world every year (WHO 1990). Most of these occurrences happen in developing countries (Ecobichon 2001; Kumar et al. 2013) and especially among farmers (Jørs et al. 2006). Heavy metals are a group of elements formed by dense metals and metalloids characterized by their potential toxicity. These elements are toxic at very low doses and non-biodegradable with a very long biological half-life. In Latin America, it is estimated that the population at risk of being affected by heavy metals is over 4 million, mainly distributed in countries such as Argentina, Chile, El Salvador, Mexico, Nicaragua, and Peru (Bundschuh et al. 2008). Toxicity effects can be divided into two categories: acute effects and chronic ones. Acute effects appear immediately or shortly after exposure. While chronic effects may manifest many years later and their etiological origins are often difficult to trace (Farcas et al. 2013).

Pesticide handling in farming activities involves substantial health hazards to rural population and to the environment. Some variables taken into consideration when researching pesticide exposure or pollution related to farming activities are purchasing, selection, transportation, storing, formulation, application and disposal of residues and wastes. Obsolete pesticides are banned by local and international laws. The Food and Agriculture Organization (FAO) describes obsolete pesticides as those that can no longer be used and therefore require disposal. These include banned, expired, unlabelled, and/or unidentified pesticides in all forms including liquids, powders, granules, emulsions, and/or gasses as well as empty and contaminated pesticide containers and contaminated soil buried either in engineered landfills or in shallow open or closed pits (FAO 2001). Currently, the elimination of obsolete pesticides is a serious issue for governments, especially in developing countries where often the political instability causes difficulty to enforce restrictive legislations recommended by international agreements such as Rotterdam and Basel Conventions (UNEP 2011; UNEP and FAO 2010). In developing countries, once a pesticide is considered obsolete, manufacturers or merchants often abandon them with improper methods of storage leaving the pollution exposed to their effects.

Heavy metals are natural constituents of the earth crust and are persistent environmental pollutants since they cannot be degraded or destroyed. Most heavy metal pollutants originate from anthropogenic sources such as discharges of untreated domestic and industrial wastewater, accidental chemical spills, direct soil waste dumping, and residues from some agricultural inputs (Kamal 2004; Micó et al. 2006) because pesticides and fertilizers can often contain arsenic or heavy metals (e.g., Buzási-Győrfi et al. 1992; Mortvedt 1996; Zoffoli et al. 2012). Heavy metals have been detected in the biosphere, sediments, and water. These elements can enter the body system through food, air and water, and bioaccumulate over a period of time (Frías-Espericueta et al. 2010). Heavy metals have been associated with environmental degradation and different human diseases (Micó et al. 2006).

El Salvador is a developing country in Central America with volcanic landscapes and large agricultural areas. The country has the largest population density of continental America (304 hab/km$^2$) (MINEC 2015). The environment is heavily damaged with deforestation related to farming activities and urbanization. Uncontrolled pollution from urban, industrial, and agricultural activities contributes to the environmental degradation. A poor environmental legislation and weak enforcement exacerbates the problem. The rural Salvadoran population lives in poverty with only partial access to basic services. Traditionally, agriculture was the main production sector of El Salvador. Nontraditional agriculture, such as sugarcane, coffee, cotton, and grain production, has coexisted with a more diversified traditional agriculture since the nineteenth century. During the last 50 years, large amounts of pesticides have been used. Pesticide imports have increased every year (Jenkins Molierí 2003). Farmers have received little technical training and perform inadequate pesticide handling practices (Haque and Freed 1975; OPS and MINSAL 1998). Due to this mismanagement, farmers and rural population have been highly exposed to hazardous chemicals. Between 2007 and 2012, the Ministry of Health of El Salvador (MINSAL Spanish acronym) registered 9981 cases of acute poisoning, with a majority of them occurring in rural areas and predominantly in young men (MINSAL 2015).

Due to the massive use of agrochemicals, obsolete pesticides have been an emerging issue in El Salvador after the Central American cotton crisis (Murray 1994). The sudden decrease in cotton production occurred at the same time that worldwide banning of highly toxic pesticides such as DDT or toxaphene which were highly used in El Salvador. Large stocks of obsolete pesticides were left abandoned in the region. Recently, Ministry of Environment and Natural Resources of El Salvador (MARN Spanish acronym) identified several stockpiles of obsolete pesticides, some of them stored in improper conditions (MARN and PNUD 2012).

Previous studies carried out in Salvadoran rural communities (García-Trabanino et al. 2002; Orantes et al. 2011; Peraza et al. 2012) identified a high prevalence of the so called Chronic Kidney Disease of nontraditional causes (CKDnt). These studies showed that the epidemic affects mainly male farmers. Nevertheless, this illness also affects women in a lesser degree, even some women not involved in agricultural work (Herrera et al. 2014). The disease can not be explained by traditional causes such as diabetes mellitus and hypertension (Orantes et al. 2014). This type of disease was described as a chronic interstitial nephritis related to environmental and occupational toxicity which they are enhanced by hard labor conditions of the farmers (Herrera et al. 2014). This disease has been identified with high prevalence in other countries in Central America (Laux et al. 2015; Lebov et al. 2015; PAHO and WHO 2013), as well as in other tropical countries such as Sri Lanka and India (Herrera et al. 2014). The origin of this nephritis has been identified as multi-causal. However, in Sri Lanka, researchers have identified risk factors such as exposure to pesticides and heavy metals together with the intake of hard water containing arsenic. Other risk factors include dehydration and heavy work conditions that enhance the effects (Jayasumana et al. 2013).

Loma del Gallo is a Salvadoran small rural community located in San Luis Talpa coastal plain (Fig. 1). During the eighties, a former pesticide factory called Quimica Agricola Internacional S.A. de C.V. (QUIMAGRO Spanish acronym) stored stockpiles of obsolete pesticides in the community in very poor conditions. A high prevalence of CKD of 25.4 % among adults was identified in the community in 2013 (Personal communication Susana Zelaya from National Institute of Health El Salvador). Media and municipal government related this large prevalence to the chemical stockpiles, creating great social alarm among the local population (La Prensa Gráfica 2014a, 2014b). In December 2014, MARN removed the obsolete pesticides from the factory but did not clean the soils or assessed the heavy metal contamination in groundwater, taken into account, that this community did not have water system supplies, and the main source for the drinking water was home wells. For that reason, MINSAL initiated environmental and health studies to try to understand the reason of this epidemy. This investigation is the first approach to identify in the environment of Loma del Gallo some possible factors that could be contributed to the precarious health of the inhabitants (e.g., the presence of heavy metals and arsenic, and identification of spots of pesticide that have been left in the abandoned factory). However, it is not the purpose to correlate the heavy metals or the remnant pesticides with CKD because that requires a medical approach and identification of the contaminants in the patients.

The coastal plain of El Salvador has a tropical climate with a dry season (November–April) and a wet season (May–October) (MARN 2015). The geological map of El Salvador (Weber et al. 1978) identifies Loma del Gallo bedrock as acid volcanic rocks of Cuscatlán formation of Pliocene-Pleistocene age overlaid by Holocene acid pyroclastic belonging to San Salvador formation. In the flat areas of the community, there is a variable thickness (0.5 to 1.5 m) of Holocene alluvial materials, and the two soils of the study area are classified as non to low permeability (ANDA and COSUDE 2008). The permeability of the alluvial deposits increases southwards. The area is crossed by the littoral road. The majority of the homes of the community are located at the southern side of littoral road and they are surrounded by sugar cane fields to the south and to the east, and by the Orcoyo River to the west. There are small agricultural areas with corn, beans, and *Tectona grandis* trees in the area of the community. QUIMAGRO was located to the North of the littoral road (Fig. 1). This closed factory stored 34.6 T of abandoned obsolete pesticides for more than 30 years.

This study describes the problem of pesticide contamination from the former pesticide factory based in our visual inspection, and the concentration of heavy metal contamination presents in groundwater and surface water. The agricultural workers of this community are also exposed to agrochemicals in their agricultural practices. In this work, we include the results of a pesticide handling process carry out by the farmers. Inadequate handling of pesticides applied to their crops could be contributing to the health hazards of the population. The aim of this research is to describe the different types of exposure to pesticides and heavy metals of the population of Loma del Gallo community, considering both environmental and occupational exposure. An investigation of pesticide contamination in the soils and water of Loma del Gallo is underway.

## Methods

### Study design

This is a descriptive cross-sectional study carried out during 2013–2014 consisting of (1) an inspection in the QUIMAGRO former pesticide factory area, (2) analysis of water samples of the community wells and nearby streams, and (3) a structured survey to local population about their perceptions of pesticide exposures in the community.

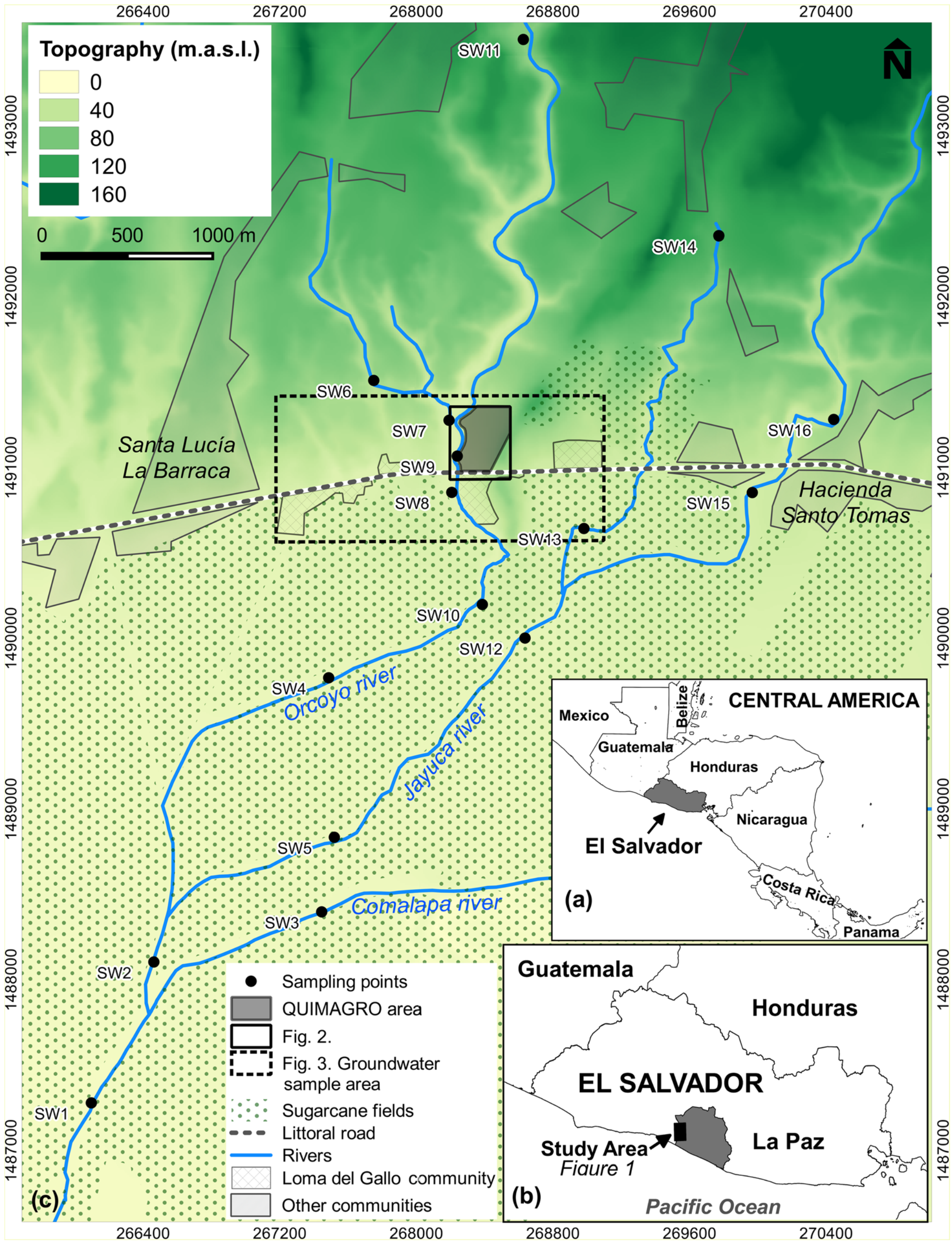


**Fig. 1** **a** Location of El Salvador in Central America. **b** Location of the studied area in El Salvador. **c** Location of the surface water sampling sites, QUIMAGRO factory, Loma del Gallo community, and location of groundwater sampling sites

## Field inspection

In December 2013, a field inspection of the former pesticide factory was performed. This inspection was carried out in coordination with local health authorities, who obtained the signed and sealed official permit. The place is completely fenced and with permanent private security, access is completely restricted and the area can be visited only with permission from the authorities. This permit request includes an explanation of the purpose of the visit to the facility. Pesticide storage, chemical dumping, and waste in the former plant were described and geo-referenced.

## Water sample collection

Between November 2013 and April 2014, water sampling was conducted to evaluate basic physical and chemical properties and heavy metal content. During the sampling process, pH value was measured in situ using portable instruments (ExStik® EC500 and YSI Model 556). Water hardness and heavy metal content (i.e., arsenic, cadmium, chromium, lead, zinc, and copper) of each sample were analyzed in the National Reference Laboratory of MINSAL. Polypropylene recipients with a capacity of 1 l with a nitric acid solution of high purity to prevent loss of metals by container adsorption and sample precipitation were used to collect the water samples. For surface water sampling, the collection container was submerged into the water carefully to avoid contamination from land and surface debris. Sampling of the groundwater was done using a horizontal Van Dorn beta sampler and then the sampling bottles were filled with the collected sample. All samples were stored in ice with the temperature of 4 °C for transporting to the laboratory. Surface water samples were collected from 18 sampling points in the Orcoyo River, Jayuca River, Comalapa River, and three minor streams near to Loma del Gallo community (Fig. 1). Groundwater samples were collected from all wells of the community that were 13 hand-dug home wells, with a maximum depth of 37 m and a minimum of 22 m. All sampling sites were geo-referenced.

The surface water sampling points were chosen based on the experience of the authors, considering the presence of tributary flows and runoff, in order to characterize the flow upstream of the factory, the community studied and sugar cane fields; flows next to the community and flows downstream of the community and in the areas of the sugar cane fields. Also, the access to the sampling point was taken into account, since in some cases, the vegetation was so thick it was impossible to access. Finally, the safety of researchers was taken into account due to the violence currently affecting El Salvador. The researchers agreed to collect samples from areas that the local staff of MINSAL Health Center indicated as safe.

### Chemical analysis

Identification and quantification of heavy metals were carried out in a Atomic Absorption Spectrophotometer (AAS) with graphite furnace AAnalyst 800 Zeeman model. Arsenic (As), cadmium (Cd), chromium (Cr), and lead (Pb) were analyzed by graphite furnace technique. Zinc (Zn) and copper (Cu) were analyzed by the flame technique. Both the analysis conditions and determination of hardness water were conducted according to APHA Standard Methods (APHA 1999).

### Mapping

Geo-referencing was carried out through a Garmin Montana 650 Global Position System (GPS) device using the ellipsoidal reference system World Geodetic System 84 (WGS 84) and Universal Transverse Mercator (UTM) projection. Results of the samples analysis were digitalized and stored in a PostGIS database (postgis.net). Quantum GIS 2.0 Dufour (www.qgis.org) was used to develop the presented maps.

### Questionnaire and surveyed population

A structured questionnaire to collect information about perceptions of the local population regarding environmental and occupational pesticide exposure was elaborated. The questionnaire consisted of four sections: the first section was about the demographic data of the people interviewed, the second section was directed to know the exposure to pesticides of all the people interviewed, the third section was directed to stud the exposure to pesticide of the agricultural workers in the group, and the fourth section was about the occupational exposure of former QUIMAGRO workers.

Before applying this survey in Loma del Gallo, a pilot survey was handed out to ten people in a neighboring community with similar characteristics in order to evaluate the adequacy of the questions. The final survey was conducted from January to March 2014. Data collection was carried out home to home with the help of the personnel from MINSAL local health center. Interviews took 30 to 45 min to be fulfilled. Before the interview, the objectives of this study were orally explained and a consent form was signed by each participant.

Target population was the whole community of 18 years of age or older. According to 2013 census of the MINSAL's local health center, Loma del Gallo had 110 inhabitants 73 of which were 18 years old or older. The final size of the studied sample was 41 inhabitants. The remaining population was not interviewed due to the migration produced by social alarm and other factors such as people with working activities outside the community and one recent death. These factors resulted in 32 inhabitants who could not be surveyed.

### Compilation of complementary information

A database of pesticides and other chemicals stored in QUIMAGRO factory was obtained from MARN, which monitors the stockpiles of obsolete pesticides of El Salvador.

### Statistical analysis

Data was digitalized in a Microsoft Excel 2010 spreadsheet and a descriptive statistic analysis was carried out using R 3.2.1 statistical software. For environmental data and some quantitative variables collected through the questionnaire, minimum, maximum, mean, and standard deviation values were calculated. For qualitative variables collected through the questionnaires, frequencies were obtained. The results were ordered in a frequency and percentage table.

## Results

### QUIMAGRO pesticide plant inspection

Six buildings constituted the former pesticide plant. A laboratory facility, three warehouses, a water close (WC) facility, and a guardhouse were identified (Fig. 2). In general, grass and weeds covered the whole area of the factory. Chemical residues improperly stored in lab facilities were

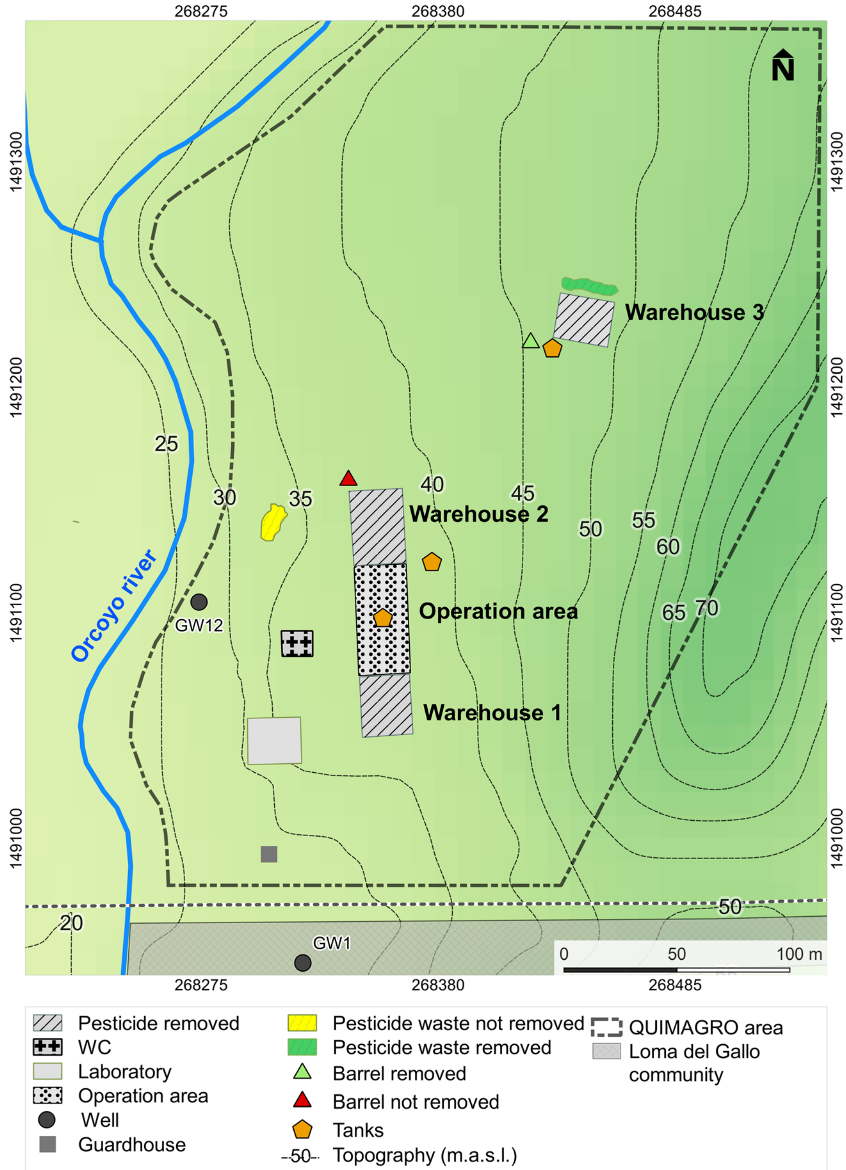


**Fig. 2** Location of facilities and heaps of chemical waste in the Química Agrícola Internacional, S.A. de C.V. (QUIMAGRO) pesticide factory area

identified. In the northern warehouse (warehouse 3 in Fig. 2), metal and plastic containers full of chemicals were placed on wooden pallets. Some of these metal containers were damaged due to corrosion and they generated chemical spills. According to the MARN (2013), these barrels contained 34.6 tons of chemicals. The barrels contained 2.3 tons of methamidophos and monocrotophos, 17.7 tons of ethyl parathion and metyl parathion, 3.8 tons of toxaphene, 1.5 tons of chlordimeform, 0.2 tons of quimation, 3.9 tons of solvents such as acetone, metyl glycol, and xylene, and 5.2 tons of sponto a family of emulsifiers. Table 1 lists all the chemicals found in QUIMAGRO identifying each one according to commercial name (substance), CAS (Chemical Abstracts Service) number. The toxicity hazard according to the WHO (2009), water solubility and degradability in soil are also listed.

As it is shown in Fig. 2, outside of the warehouse 2, two corroded metal barrel were found. At southeast of this warehouse, a buried deposit was found where xylene was stored (personal communication Ítalo Córdoba from MARN). On the north side of warehouse 3, an accumulation of chemical wastes were identified. The atmosphere was unbreathable because of the strong odor produced by pesticide wastes inside the buildings and surrounding areas of warehouse 3. Westwards of warehouse 2, in the slope to the river Orcoyo, chemical waste that was partially buried was identified.

## Groundwater analysis results

Water hardness values range from 19 and 247 mg/l, with a mean of 67 mg/l. The maximum value occurs in a well located within the community. Factory well and some wells placed in

**Table 1** Information about chemicals stored in QUIMAGRO factory and pesticide applied by farmers

| Substance | CAS number | Acute toxicity hazard (WHO 2009) | Water solubility | Degradability in soil | Source |
|---|---|---|---|---|---|
| Metamidophos[a,f,g] | 10265-92-6 | Ib | Extremely soluble (FAO 2000) | Very degradable (INECC 2015) | QUIMAGRO and Used by farmers |
| Monocrotophos[a,f] | 6923-22-4 | Ib | Very soluble (INSHT 1994) | Slightly degradable (FAO 2000) | QUIMAGRO |
| Ethyl parathion/ parathion[a] | 56-38-2 | Ia | Slightly soluble (INSHT 2013) | Very degradable (FAO 2000) | QUIMAGRO |
| Quimathion/ methyl parathion[a,g] | 298-00-0 | Ia | Very soluble (IPCS INCHEM 1993) | Extrmely degradable (FAO 2000) | QUIMAGRO and Used by farmers |
| Toxaphene[a,f] | 8001-35-2 | O | Slightly soluble (FAO 2000) | Slightly degradable (FAO 2000) | QUIMAGRO |
| Chlordimeform/ clorfenamidina[a,f] | 6164-98-3 | O | Extremely soluble ( FAO 2000) | Slightly degradable (FAO 2000) | QUIMAGRO |
| Sponto [d] | 26027-38-3 | III | Insoluble (U.S. EPA 2014) | Very degradable (Soares et al. 2008) | QUIMAGRO |
| Xileno[e] | 1330-20-7 | U | Insoluble (U.S. EPA 2014) | Very degradable (NCBI 2015) | QUIMAGRO |
| Metil Glicol[e] | 109-86-4 | III | Extremely soluble (ATSDR 2010) | Very degradable (NCBI 2015) | QUIMAGRO |
| Acetone[e] | 67-64-1 | U | Extremely soluble (JML plc 2002) | Very degradable | QUIMAGRO |
| Paraquat[b,g] | 4685-14-7 | II | Extremely soluble (Centro de Información del Paraquat 2015) | Slightly degradable (FAO 2000) | Used by farmers |
| Atrazine[b] | 1912-24-9 | U | Extremely soluble (Belden and Lydy 2000) | Slightly degradable (FAO 2000) | Used by farmers |
| Methomyl[a,g] | 16752-77-5 | Ib | Extremely soluble (INECC 2015) | Very degradable (INECC 2015) | Used by farmers |
| Phoxim[a] | 14816-18-3 | II | Very soluble (INECC 2015) | Extremely degradable (Parasitipedia.net, 2014) | Used by farmers |
| 2, 4 D[b] | 94-75-7 | II | Extremely soluble (Haward 1991) | Extremely degradable (RA-PAL 2007) | Used by farmers |
| Chlorpyrifos[a] | 2921-88-2 | II | Slightly solubility (WHO 2004) | Very degradable (WHO 2004) | Used by farmers |
| Glyphosate[b] | 1071-83-6 | U | Extremely soluble (Barja and Dos Santos Afonso 2005) | Extremely degradable (Ramirez-Rubio et al. 2013) | Used by farmers and aircraft applied |
| Malathion[a,g] | 121-75-5 | III | Extremely soluble (INECC 2015) | Extremely degradable (INECC 2015) | Used by farmers |
| Diuron[b] | 330-54-1 | U | Very soluble (INECC 2015) | Slightly degradable (INECC 2015) | Used by farmers |

[a] Insecticide

[b] Herbicide

[c] Fertilizer

[d] Emulsifier

[e] Solvent

[f] Banned in El Salvador since 2000 (MAG, Ministerio de Agricultura y Ganaderia 2000)

[g] Aerial application restricted in El Salvador (MAG, Ministerio de Agricultura y Ganaderia 2004)

the center of the community (identified with the code GW2, GW7, GW8) presented moderately hard to hard waters decreasing southwards. Groundwater can be considered almost neutral with a pH varying between 6.1 and 7.3. Arsenic was detected in 8 of the 13 sampled wells. The highest value of arsenic is 0.012 mg/l which was found in a well located in the former plant, while the mean was 0.0049 mg/l (±0.004 mg/l). Cadmium was detected only in two wells. The highest value of cadmium was 0.004 mg/l and was found in a well located in the sugar cane fields at east side of the community (Fig. 3). Concentration of the other analyzed heavy metals such as lead and zinc was under the quantification limit of the laboratory equipment (Table 2). Copper and chromium were detected only in one well each, with values of 0.01 mg/l (GW13) and 1.5 mg/l (GW12), respectively. Note that GW12 which is adjacent to QUIMAGRO has also detectable As (0.012 mg/l).

### Surface water analysis results

Sampled surface waters can be described as soft waters with hardness ranging from 30 to 71 mg/l. These waters are classified as neutral with pH ranging from 6.9 to 7.9 with an outlier of 10 in a sampling point located at North West of the QUIMAGRO factory. Arsenic was detected in all surface

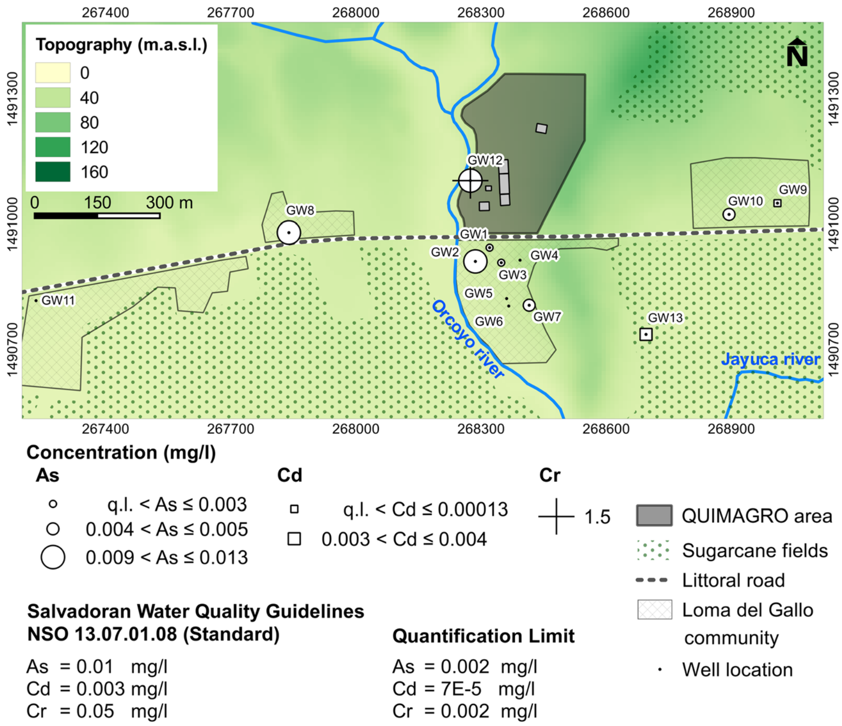


**Fig. 3** Location of wells where groundwater sampling were obtained. The *circle* shows the arsenic concentrations, the *square* shows the cadmium concentration, and the *cross* shows the chromium concentration. The *dots* show the wells location and where the values found was below quantification limit

water samples. Cadmium was detected in five surface samples downstream from the factory to the south of the community in the sugar fields (Fig. 4) with a range from 0.00008 to 0.0001 mg/l, in the streams crossing the sugar cane plantations, with the highest value in SW1; the sampling point in the stream formed by the confluence of the three rivers. These results for Cd suggest that the sugar cane plantation could be the source of Cd. Arsenic was present in all sampled points within a range 0.007–0.026 mg/l. The highest value for As is in SW14 to the NE and upstream from QUIMAGRO. Values of As are variable in all the region and could be produced by the volcanic origin of the soils in this region. Concentration of the other heavy metals such as copper, lead, and zinc were under the quantification limit of the laboratory equipment (Table 2). Similar to Cd, Cr was detected only in three sites located within the sugar cane fields (SW1, SW4, and SW5 with values 0.0041, 0.0068, and 0.0025 mg/l, respectively). Ranges of main analyzed parameters are given in Table 2. The completed results of groundwater and surface water samples taken from wells are show in Table 3 (online resource 1).

## Questionnaire results

All interviewed participants acceded to answer the questionnaire. Twenty-three of the participants were women and eighteen were men, with age ranging between 19 and 24 years. Eighteen had primary education, nine were illiterate, and six of the interviewed had secondary education. Of the forty-one participants, seventeen were farmers. Time of residence in the community varies between 0.3 and 56 years. The majority

**Table 2** Ranges of analyzed parameters and laboratory equipment quantification limit for each parameter

| Item | Groundwater | | Surface water | | Laboratory equipment quantification limit (mg/l) |
|---|---|---|---|---|---|
| | Min (mg/l) | Max (mg/l) | Min (mg/l) | Max (mg/l) | |
| As | <q.l. | 0.013 | 0.007 | 0.026 | 0.002 |
| Cd | <q.l. | 0.004 | <q.l. | 1E-4 | 7E-5 |
| Cu | <q.l. | 0.010 | <q.l. | <q.l. | 0.022 |
| Cr | <q.l. | 1.500 | <q.l. | 0.0068 | 0.0017 |
| Pb | <q.l. | <q.l. | <q.l. | <q.l. | 0.004 |
| Zn | <q.l. | <q.l. | <q.l. | <q.l. | 0.158 |
| Hardness water | 18.6 | 247.4 | 29.8 | 70.7 | 9.66 |
| pH | 6.0 | 7.3 | 6.9 | 10.0 | 4.010 |

*<q.l.* below quantification limit

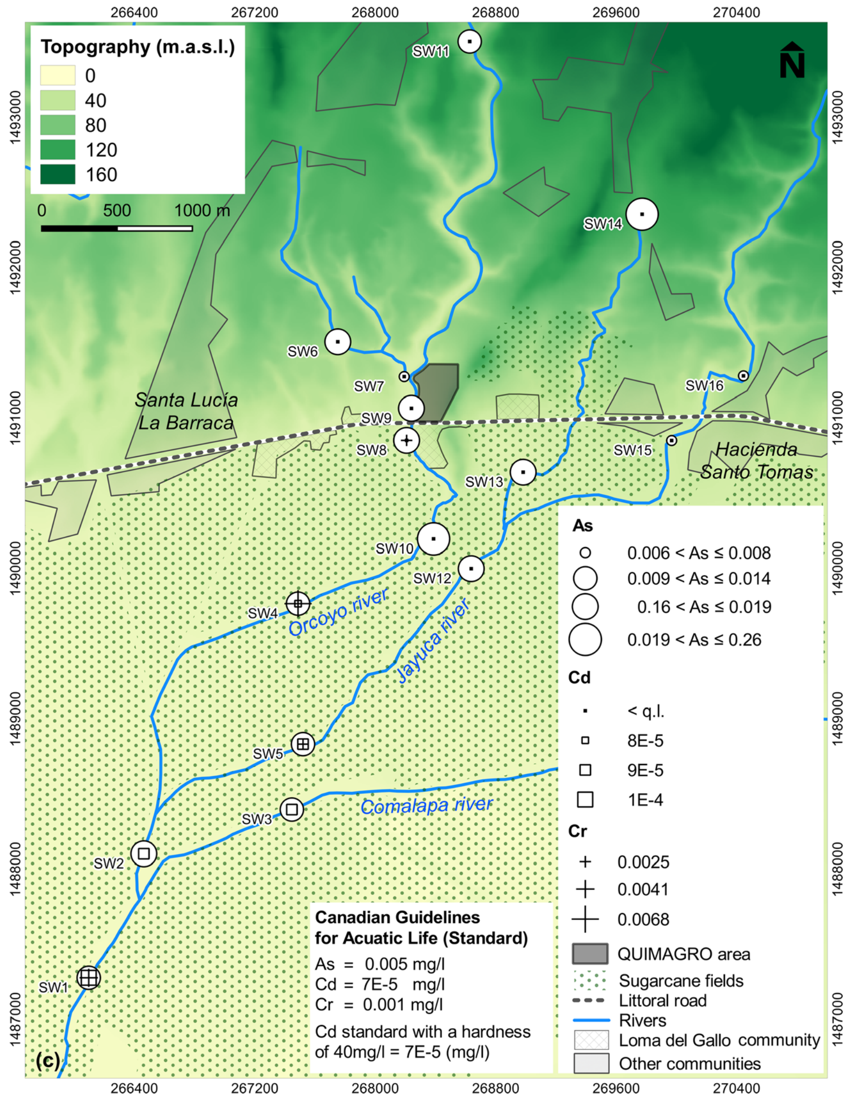


**Fig. 4** Arsenic, cadmium, and chromium concentrations identified in surface water sampling points

twenty-nine of interviewed people had at least one family member working in agriculture. In addition, seven worked in the former factory: four of them are currently farmers. The complete profile of the occupational pesticide management is shown in Table 4 (online resource 2).

*Occupational pesticide management*

**Farmers** Of the seventeen farmers, sixteen are men and one is a woman. Thirteen practiced agriculture for more than 10 years. All farmers cultivated corn. Three cultivated beans and two cultivated sugar cane. Thirteen farmers selected pesticides according to effectiveness, three farmers selected pesticides according to price, and one farmer selected pesticides according to toxicity. Ten of farmers read the pesticide label at the moment of purchase. Farmers used 19 different pesticide products comprising of 11 active ingredients. These included 6 insecticides and 5 herbicides. The active components used by farmers are included in Table 1 where each pesticide is described according to commercial name (substance), CAS number, toxicity according to WHO, water solubility, and degradability in soil.

The most used active ingredients were paraquat (65 %), methamidophos (35 %), and atrazina (29 %). According to WHO risk classification (WHO 2009), 9 % of the pesticide commonly used are extremely hazardous (Ia), 18 % are highly hazardous (Ib), 36 % moderately hazardous (II), 9 % are slightly hazardous (III), and 28 % unlikely to presented acute effects (U).

Eleven farmers stored pesticides at home. Out of the surveyed farmers, five mixed different pesticides, five make the mixture in the application place, and two mixed pesticides at home. The blends made by farmers were paraquat and atrazine, cypermethrin and fertilizers, atrazine and diurón, and 2.4 D and atrazine. All farmers used manual spray backpack pumps to apply pesticides. Thirteen farmers washed the pump after the pesticide application. Ten percent of farmer participants abandoned the empty pesticide containers in the cultivated fields, five buried the empty pesticide containers, three burned the pesticide containers, and one farmer would wash and reuse the empty pesticide containers. Nine of farmers stored the pesticides leftover for reuse, two applied remnants in surrounding areas immediately after the pesticide application. Fourteen farmers did not use personal protective equipment (PPE). Fifteen farmers washed their clothing after the application of pesticides but two of them do not wash their clothing after application of chemicals. Sixteen farmers drank water during the pesticides workday and took the food in the field crops area. Two farmers smoked during the pesticide application. The complete profile of the occupational pesticide management is shon in Table 5 (online resource 3).

**Former QUIMAGRO workers** Interviewed QUIMAGRO workers did not used PPE during their working activities. QUIMAGRO former workers reported that they were in contact with methyl parathion, malathion, aldrin, methomyl, methamidophos, toxaphene, acetate, acetone, and sponto. These chemicals are described in Table 1. The complete results of pesticide exposure to QUIMAGRO workers are shown in Table 6 (online resource 4).

## Discussion

For more than 30 years, QUIMAGRO warehouses stored hazardous chemicals including pesticides classified as extremely hazardous (Ia), highly hazardous (Ib), or obsolete (O) by (WHO 2009). Moreover, surfactant and solvents stored in the former plant, identified as slightly hazardous (III) by WHO, were also a risk to human and environmental health. For example, methyl glycol has been associated to health problems to human and to laboratory animals (ATSDR 2010). Chemical waste identified in the former laboratory and in heaps lying at different areas should be considered as a probable hazardous risk. In addition, hazardous pesticides are recurrently applied to closer crop fields. These pesticides could be connected to several health issues. The most used pesticides by local farmers are paraquat, classified as moderately hazardous. Previous studies in El Salvador also identified paraquat among the most used pesticides (Kato et al. 2002; Mejía et al. 2014). Paraquat is a cheap herbicide that has been related to several health problems as Parkinson disease and damage to the kidneys, liver, and esophagus (Goldman et al. 2012; Wesseling et al. 2001). According to interviewed inhabitants, the air application of glyphosate is recurrent practice in closer sugar cane fields. Glyphosate is an herbicide used as maturant in the sugar cane crops (CENGICAÑA 2014) classified as U according its toxicity but classified by the WHO as possible highly carcinogen to human (2 A) (WHO and IARC 2016).

Arsenic, cadmium, and chromium, three elements classified commonly as toxic heavy metals, were identified in the community groundwater with concentrations reaching levels above the standards proposed by Salvadoran Consumption Water Quality Guidelines (CONACYT 2009), so that water intake from some wells can be considered as a source of the exposure for local population. Arsenic and cadmium were identified in surface water reaching concentration levels above the Canadian Water Quality Guidelines for Protection of Aquatic Life (As 0.005 mg/l, Cd 7E-5 mg/l) (CCME 2002), which implies serious threats to local biorganisms. The highest groundwater concentrations of arsenic and chromium in the former chemical plant well suggests that it was a source of heavy metal water pollution. The presence of higher values of hardness in waters obtained in the factory and in closer housings also suggests the former plant as a source of ground water pollution. Common pesticides used fairly extensively in agriculture and horticulture in the past contained substantial concentrations of metals (Gimeno-García et al. 1996). Moreover, there is a presence of high arsenic concentrations in all the surface water samples including the ones obtained upstream of the QUIMAGRO. This condition implies a probable contribution of geological background to the water pollution. In El Salvador, geogenic arsenic water pollution is produced because of the enrichment of geothermal fluids with this element are mixed with water from cold aquifers or surface waters (López et al. 2012). A study carried out by MARN (MARN 2006) obtained similar arsenic concentrations in the Comalapa River with values ranging from 0.0004 to 0.0079 mg/l. In the Jiboa River, located few kilometers northeastwards of the study area, values ranging from 0.0023 to 0.1230 mg/l were found. Other studies carried out in Ilopango Lake, a lake filling a volcanic caldera located 20 km upstream from the community, showed high arsenic concentrations with values ranging 0.15 to 0.789 mg/l (López et al. 2012). Cadmium water pollution identified in sampling points located in or close to sugar cane fields could be related to agrochemicals applied to sugar cane crops (Vitória et al. 2001). Commercial phosphate fertilizers, widely used in sugar cane during planting process in El Salvador (López-Guido and Zavala-Chávez 2010), generally contain small amounts of cadmium as impurity (Mortvedt 1996).

Some of identified hazardous pesticides stored in the former factory such as toxaphene and some pesticides currently used by local farmers such as paraquat, atrazina, and diuron are only slightly degradable in soil which implies that they are persistent in the environment and therefore they will have long-term effects. This is especially important in the former factory where large spills of pesticides were identified. Erosion and transportation processes could disseminate these substances in a wide area endangering the community. Erosive processes have a particular impact on the heaps of chemical wastes at outdoor conditions. Runoff produced by flash floods, a common process in El Salvador coastal area (Fernández-Lavado et al. 2007), can remobilize chemical waste particles, transport them downslope, and disseminate them in the Orcoyo River or in the community area. This is especially important on waste heap located to the west of the facilities because it is located in a 6 % slope that drains directly to the Orcoyo River. The majority of the used pesticides are very soluble in water, which favors its dispersion through surface waters and groundwater. Volatilization and wind erosion are processes that should be taken into account in order to evaluate pollution dispersion. Pesticide stockpiles and heaps of chemical wastes are sources of odor pollution which evidences volatilization processes. Perceptions of odors coming from the former factory and from surrounding field crops during pesticide application are evidence that airborne applied pesticides produce volatilized substances. Although odor pollution of air does not mean necessarily hazardous pesticide pollution, it can affect mental attitudes, enjoyment of the environment, and contributes to social alarm (Brown et al. 2000). During aircraft application of pesticides, pesticide drift is very high, about 30 % of pesticides applied is lost by wind or air drift (Van Den Verg et al. 1999). Minimum distances and no natural barriers among community and sugar cane fields convert aerial spraying in a major determinant of exposure of the entire population. Several studies have identified higher concentrations of pesticides in dust in rural households than in reference homes (Curwin et al. 2005) which imply higher exposure to population in farming areas. In El Salvador, an indiscriminate aerial spraying application of pesticides has been carried out since mid-twentieth century (Murray 1994); however, aerial spraying of pesticides was not regulated until the Agreement 423 of Ministry of Agriculture and Livestock published in 2011 (MAG 2012). This exposure could be exacerbated because most of the community households store improperly the pesticides. In this community, there is a false perception that pesticides hanging in the trees is a safe form of storage. This method is viewed as a safe form of storage because it is kept out of reach from children. Extreme weather conditions characterizing the tropical climate (e.g., high insolation and heavy rainfalls) can degrade pesticides causing them to lose their effectiveness. Plastic bags (usually supermarket bags are used to store the chemicals) are easily damaged also by extreme weather conditions and by local fauna like birds or mice, producing local toxic spills.

Occupational exposure to pesticides is a fact among agricultural workers and former factory workers in Loma del Gallo. The majority of interviewed farmers did not wear any PPE during pesticide handling operations. Wearing proper PPE can greatly reduce the potential for dermal, inhalation, eye, and oral exposure. Present results are consistent with other studies showing that the use of PPE among farmers appears to be poor or it is used incorrectly in many parts of the world (Matthews 2008), especially in developing countries (Mejía et al. 2014; Snelder et al. 2008). Usually, PPE is impractical in tropical climate conditions or unaffordable for low income population as family farmers (Konradsen et al. 2003). Manufacturers provide safety instructions, including information about what PPE should be wear, in pesticide container labels, and in safe data sheet (SDS). However, 16 interviewed farmers can read and 7 of them have an education higher than basic school, and 7 interviewed farmers do not read pesticide labels or SDS. A recent study carried out in Brazil (Waichman et al. 2007) identified lack of clarity of the information provided in the product label as the main limitation to read or to understand the labels. Brazilian farmers perceived the information on the labels as too technical, not written in plain language, and the fonts used were often too small, making reading difficult.

The obtained results confirm that there is a lack of technical training of farmers on the proper use of pesticides as was mentioned in the introduction. These results are consistent with former studies carried out in other developing countries, too (Barraza et al. 2011; Blanco-Muñoz and Lacasaña 2011; Snelder et al. 2008). In El Salvador, *Decree 89 - General Regulations to Prevention of Risks in the Workplace* regulated by the Ministry of Labor and Social Welfare (Gobierno de El Salvador 2012) require all workers including the self-employed, who are exposed to hazardous chemicals, such as pesticides, to be trained regarding their occupational exposures. This training should include pesticides handling in all of the stages and the use of PPE. Even though provision of training is the responsibility of the employer, in small-scale farming where farm owners have considerable financial constraints, implementation of occupational health and safety legislative requirements is generally unlikely. Salvadoran government should establish standard training programs, which should include awareness of the specific risks of pesticides and the need of special accreditation for using hazardous pesticides. Licensed applicators are necessary for safe use of hazardous pesticides. For example in the USA, Agricultural Worker Protection Standard (WPS), established by US Environmental Protection Agency (EPA), provides standard requirements for pesticide handling and training at federal level (EPA 2015a). On the other hand, each US state provides training and certifications that limits the use of restricted pesticides to individuals successfully completing a certification course according to WPS standards (EPA 2015b). Although El Salvador lacks the necessary bureaucratic infrastructure to enforce national laws, government, regulatory authorities, international agencies (FAO, ILO, PAHO, etc.), NGOs, and industry, all have to cooperate to enforce these working standards facilitating the access of all farmers to training programs regardless its economic level or location. Finally, authorities must make an effort to develop alternatives to massive pesticide use like integrated pest management (IPM). IPM is an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimize the use of pesticides (FAO 2015). In Nicaragua, farmers trained on IPM practices have higher awareness of pesticide health risks (Garming and Waibel 2009).

The prevalence of 25.4 % CKD ($n$ = 72) in the studied community indicates that this disease is a serious health problem for this population because it is higher than the estimated 8 to 16 % worldwide (Jha et al. 2013). This is the highest prevalence obtained in rural communities of El Salvador. Other studied communities have lower prevalence, Bajo Lempa with 15.4 % ($n$ = 1215) and Guayapa Abajo with 20.5 % ($n$ = 595) reported in former studies (Orantes et al. 2014). A suburban community, Las Brisas in San Miguel, adjacent to another abandoned pesticide factory whose population was not engaged in agriculture, also showed a similar prevalence of 21.1 % ($n$ = 578) (Orantes et al. 2014). The exposure to toxics such as arsenic and cadmium, hard and moderately hard waters as identified in some Loma del Gallo wells, can be considered as a risk factor for CKD as suggested by Jayasumana et al. (2013). This author suggested that the long-term exposure to heavy metals and pesticide can favor CKD in agricultural areas (Jayasumana et al. 2015).

Although the limitations related with the descriptive characteristics, cross-sectional design, and small population of the present work, serious exposures to highly toxic substances to local population were identified. A broader chemical analysis of the different environmental phases (soil, air, and water) and in the affected population should be carried out in order to quantify more completely pesticide and heavy metal pollution and its effects.

In order to mitigate the risks related to occupational, environmental issues, prevent and control of CKD, and other diseases, a compressive approach is needed (Platz et al. 2015). This compressive approach should imply a multidisciplinary intervention involving different stakeholders as governmental institutions, pesticide industry, agriculture experts, health, and environment as well as the affected population in a collaborative environment to define solutions. Similar research effort to these oriented to evaluate and mitigate occupational risks factors among sugar cane harvesters (Crowe et al. 2015; García-Trabanino et al. 2015; La Isla Fundation 2015) should to be carried out. Interventions should include the entire community, not only agricultural workers. This interventions should ensure basic services to the local population such as safe water, to provide community tools to enforce the existing pesticide related legislation (i.e., observe buffer zones around water bodies and human settlements), to evaluate cleanup, remediation strategies of polluted areas (i.e., application of computer models for analyzing transport and fate of chemicals), or to implement selected remediation techniques, as well as to design a platform that enables transparent communication between several stakeholders and the community for disseminating awareness and understanding, or joint building of solutions.

## Conclusion

Pollution is still present in former factory QUIMAGRO area, because pesticide wastes were not totally removed. The strong pesticide odors are an evidence of the contamination in the QUIMAGRO area. High levels of Cr in a water sample from a well located in the factory area is an evidence of pollution in the area.

High levels of Cd in water samples from rivers and wells located in sugar cane fields possibly have source in agrochemicals applied to sugar cane crops. High levels of As in surface and ground waters can be related both to a regional sources (geogenic and anthropogenic sources) and to the former pesticide factory.

Local farmers mishandle pesticides in all different stages of pesticide use. Farmers use highly toxic pesticides and many of these are restricted or banned in different countries around the world due to their adverse effects to human and environmental health. Farmers and former workers of QUIMAGRO do not use PPE, this is a risk factor that increases the pesticide exposure.

The pollution identified in the environment together with pesticide mismanagement by local farmers produces a high exposure of Loma del Gallo population and environment to toxic substances. This exposure can produce serious consequences, both for humans and for the environment. Given these conditions, measures to mitigate this exposure should be taken. At the same time, the possible consequences of this exposure should be investigated. It is important to take actions to protect the population from further exposure.

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**Compliance with ethical standards**

**Conflict of interest** The authors declare that they have no competing interests.

**Research involving human participants and/or animals** This investigation include information capture of people in a rural community theought a interview, we not take any biological sample.

**Informed consent** Before the interview, the objectives of this study were orally explained and a consent form was signed by each participant. This document explain the structure of study and declares that the each participation is totally voluntary, also specified that none will receive a remuneration for participating.

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