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Heavy Metals in Agricultural Soils of San Francisco de Macorís and La Vega, Dominican Republic

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Abstract

In Dominican Republic exists cultive larges fields of various agricultural rubles. The largest extensions are rice, banana and cocoa; these are located in the Cibao Valley. In the eastern, southwestern, and a small area in the north of the country, sugar cane is cultivated. Heavy metals are found in many of these soils that could be affecting the quality of agricultural products or production. The levels of Cr, Ni, Zn, Cu, Cd, As, Hg and Pb, determined by X-ray fluorescence spectroscopy, in soils collected in two cultivation areas of Rice de La Vega and San Francisco de Macoris (SFM) have been compared with the NOAA-USEPA Canadian Agricultural Soil and Sediment Guide (CEQGs) (SQuiRTs Table). The levels of Cr and Ni in La Vega exceeded the threshold effects levels (TEL), and the probable effects levels (PEL). Pb levels in the La Vega area were higher than in SFM. In general, these metals are found in the La Vega area in higher concentrations than in SFM, exceeding PEL and TEL.

Keywords

Soil, Heavy Metals, Fluorescence X-Ray, Toxicity

1. Introduction

The production of quality food in sufficient quantity is of utmost importance to guarantee the nutrition of people around the world. To achieve this in agriculture, it is necessary for crops to obtain the necessary micronutrients from the soil to develop and bear healthy fruits that contribute to a healthy diet for those who eat them. There are plants that are capable of storing large amounts of metals in their roots, stems, leaves or fruits; that could be toxic when ingested by people in significant amounts (Raju et al., 2016). Heavy metals such as Zn and Cu are necessary for the good development of various plants, but they have a limit for safety. The excessive bioaccumulation of metals in fruits changes their texture and quality (Sepúlveda et al., 2020; Shahbaz et al., 2018; Martínez-Alva et al., 2020). In the same way, it happens with the deficiency of nutrients including some metals that are necessary for plants to carry out photosynthesis (Ali et al., 2011; Thi-Xuan et al., 2017). The Canadian Council of Ministers of the Environment (CCME) has produced a table or guide (CEQGs, Canadian Environmental Quality Guidelines) compiled in studies to rate the quality of agricultural soil by its heavy metal content. The United States Environmental Agency (USEPA) also developed the SQuiRTs (Screening Quick Reference Tables) table used by NOAA for marine sediments. This is of vital importance since a soil is considered contaminated when the concentrations of metals are higher than in soils that have not been intervened or influenced by human activities. If the metal concentrations at the time a mining area is evaluated correspond to those that existed before the mining activity began (Arranz-González & Alberruche, 2007), this area is not considered contaminated.

In the region of La Vega and San Francisco de Macorís, our study area, the soils are basically made up of clayey rocks composed of minerals moderately rich in iron, copper, chromium and nickel (Aiglsperger et al., 2015) many of them forming sulfides that have been sedimented by being deposited during floods (Fuentes-Hernández, 2019) and overflows of the Camú River, from the Upper Miocene to the Pliocene, resting on plutonic-metamorphic rocks composed of micritic limestones and andesites. In addition to the clays that were washed away by the Yuna River, these are rich in iron, nickel and iridium minerals (Garutiite); rhodium, nickel and arsenic (Zaccariniite) (McDonald et al., 2010; Vyzmalová et al., 2012), composed of igneous and Tuscan rocks as well as volcanic-sedimentary rocks, volcanic-plutonic rocks, metamorphic amphibolites and mafic intrusive volcanic rocks. This occurred from the Upper Jurassic, Upper Cretaceous to the recent Quaternary, where coarse-grained sand layers were previously deposited (Villanova-de-Benavent et al., 2016).

According to the hydrodynamics of the region, the soils that were formed by the sedimentary depositions of the Yuna River are characterized by the presence of the Ni mineral (peridotite) and other minerals composed of heavy metals such as iron and cobalt (Marchesi et al. 2016). While the soils of La Vega and San Francisco de Macorís due to the dragging of the Camú and Jima-Masipedro rivers could present high concentrations of metals, especially Ni for the same reason, a bioaccumulative element in the rice plant (AqeelKamran et al., 2016). Along the highway that goes from La Vega to SFM there are several towns and communities that influence the levels of metals through the waste of agricultural implements and domestic activities (Romic & Davor, 2003). For the study of trace metals in soils and sediments, techniques such as atomic absorption spectroscopy by flame or graphite furnace (AAS) (Pérez-Olvera et al., 2008), X-ray fluorescence (XRF) (Fernández-Ruiz, 2009), mass spectrometry (ICP-MS) (Sibello-Hernández et al., 2014) and atomic fluorescence spectrometry (AFS). XFR is a fast, inexpensive and non-destructive technique that is often used for soil and sediment analysis due to the advantages it offers over the other techniques mentioned. It is not so sensitive, being very useful when it is not required to determine very low values (Roca & Bayon, 1981). The methodology for preparing the sample for the analysis is very simple and as it is a non-destructive technique, the samples can be used for other analyzes by other techniques if there is a need to verify the results. This advantage over atomic absorption spectroscopy makes it very convenient because it does not use acids, fuels and does not generate polluting residues from combustion (Marguí et al., 2011). When determining heavy metals in agricultural soils of the study region, their presence is sought, in order to evaluate their levels. This information would help us to determine if the soils are contaminated when comparing it with the levels of the continental crust (Rudnick & Gao, 2003), by their concentrations with those that are normally present in uncontaminated soils that serve as a reference (Freedman, 2018). In addition to its impact on the possible bioaccumulation in agricultural products of wide consumption (Prieto-Méndez et al., 2009), imply damage to animal and human health that ingests it. In the Dominican Republic, very little is known about the content of heavy metals in agricultural soils, since the various studies that have been carried out on the composition of the rocks have been conducted for mining purposes, not environmental ones. Using the levels determined with this study as a baseline, it would be possible in the future to determine if there has been any degree of contamination caused by industrial, agricultural or domestic activities. Currently, although the levels of trace metals are very high, we cannot establish whether mining, industrial, agricultural or domestic activities have contributed because no information was found on the composition of the agricultural soils studied.

2. Study Zone

The study area is located in the Cibao region, between the provinces of La Vega and San Francisco de Macorís, with contributions of water from the Monseñor Noüel province, where there is a deposit of ferronickel (peridotite) that could change the quality of the water (Gjoka et al., 2010). The mineral is found in the basins of the Camú, Jima and Masipedro rivers. The Jima and Masipedro rivers are dammed in the Rincón reservoir; these waters are used to irrigate the rice plots of the western and southern part of the sampling area of this study (Lewis, et al., 2006). The use of the land is essentially dedicated to the cultivation of rice and livestock, with crops of small fields of sweet potato, cassava and banana. The smallest area corresponding to the province of La Vega has 10.6 km^2, while the largest area located within the limits of the provinces of La Vega and San Francisco de Macorís (SFC) has an area of 71.0 km^2 (**Figure 1**).

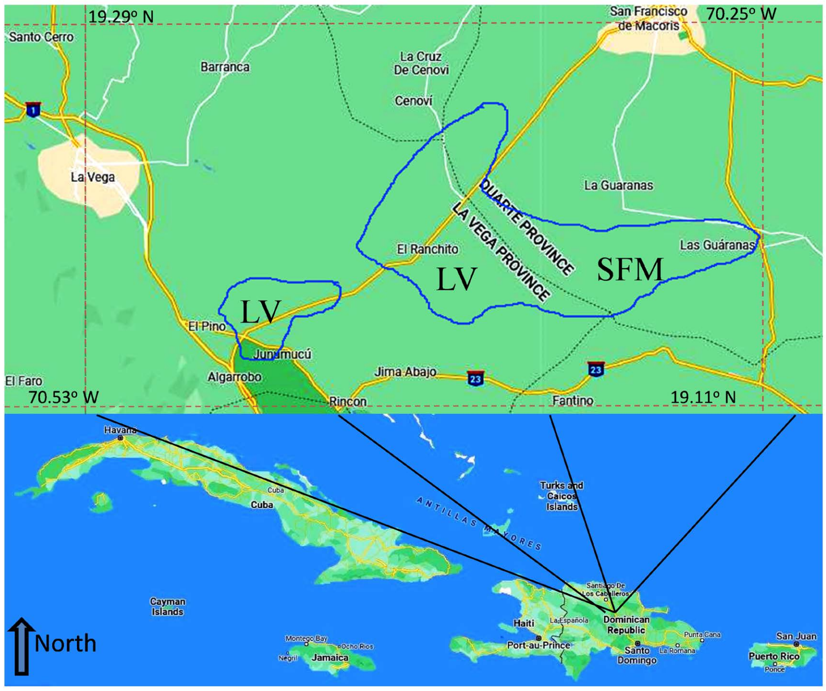

Figure 1. The blue areas are the soil sampling locations; the one on the east side located in La Vega (LV) and the one on the west of San Francisco de Macorís (SFM) between La Vega. Fuente: Google Earth.

3. Materials and Methods

3.1. Sampling

The place where each soil sample was taken was referencing with GPS, preferably at an approximate distance of 250 m within a plot. A plastic shovel was used to collect approximately 1.0 kg of soil. The samples were selected from a 15 cm column and packed in plastic bags to be transported at room temperature with the humidity conditions found in the soil. When the samples are to be carried out other tests, they must be kept refrigerated to prevent volatile elements from being lost.

3.2. Drying

The samples were dried, first at room temperature, and then to remove all the humidity in a convection oven at a temperature of 100˚C.

3.3. Sample Preparation

After drying, the samples were crushed in mortars and then sieved to 75 microns. 3.0 ± 0.005 g were taken, measured in a precision balance of 0.0001 g, with this mass of soil, using a Specac press, the sample was subjected to a pressure of 15 tons/cm^2, making a tablet with a diameter of 2.0 cm.

3.4. Analysis

The pellet was taken and placed on a Skyray EDX3600B brand x-ray fluorescence spectrometer (Delanoy et al., 2022). The excitation voltage of the x-ray emitting source was 40 kV and 600 μA. The spectrometer was previously calibrated using standard soil and sediment samples certified to ISO/IEC 17025 and ISO Guide 34 by Sigma-Aldrich (TraceCert; NIST, IAEA) and BAM-CRM (SRM1944, SRM2704, SRM1646a and IAEA356, SRM2710a). The quality of heavy metal determinations was verified using certified materials BCR277 and SRM1944. The NOAA-SQuiRTs and USEPA guideline values for marine sediments coincide with the Canadian Agricultural Soil and Sediment Guideline. For this reason we compare the Threshold Effect Levels (PEL) of a metal with the limits of the guide for a healthy soil in relation to this metal.

4. Results and Discussion

Two of the heavy metals that are important when evaluating the quality of a soil are Arsenic and Cadmium (Bravo-Covarrubias et al., 2020), are very harmful to human health (Londoño-Franco et al., 2016). These two metals in the soils analyzed in the two study regions were in all cases well below the TEL according to the agricultural soils guide, both from Canada (CEQGs) and from other countries (SQuiRTs). In the case of Mercury, only some samples show significant values, in the rest the values were below the detection limit, 0.2 mg/kg. The Zn in one sample exceeded the PEL and two the TEL, in the other samples the values were below the TEL, which in a general sense places these soils with low levels of Zn in the La Vega and SFM area, so they do not pose any risk to crops. These soils can be considered not contaminated with Zn (**Figure 2(d)**) according to the

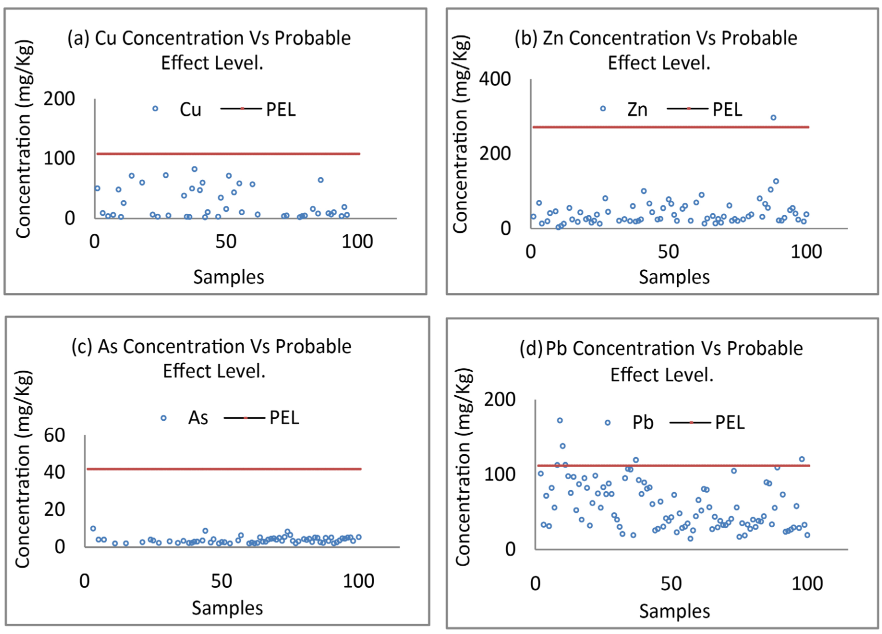

Figure 2. Distribution of Cu, Zn, As andPbin the soils sampled in La Vega and San Francisco of Macorisversus their respective Probable Effect Level (NOAA-USEPA).The Cu, Zn, As and Pb values in both cases do not exceed the Probable Effect Level.

FAO and NOAA-USEPA no need intervention its (**Figure 3(d)**). Cu, the values in the soils did not exceed the PEL, only some values exceed the TEL value in La Vega (**Figure 2(a)** & **Figure 3(a)**), so they are considered suitable as agricultural soils in terms of this metal according to the FAO. In SFM near the town a value higher than the TEL was found; all Copper values in the SFM soils are below the PEL. This value could be linked to anthropic activities in soil management (Cordero, 1979). In the La Vega area, the majority of Cr levels exceeded the PEL (**Figure 4(a)**) according to the values of the FAO, NOAA-USEPA and CCME standards; with greater attention to those located north of the road that connects La Vega (LV) with San Francisco de Macorís (SFM). The same happens with those in the LV-SFM area that exceed the guide Canadian Agricultural Soils (CEQGs) in all places and the table (NOAA-USEPA-SQuiRTs), which suggests that these soils have high concentrations of Cr (**Figure 4(a)** & **Figure 5(a)**) that could affect those crops that are sensitive to the metal; as well as being a bioavailable source for bio-accumulating crops (Mesa-Pérez et al., 2015). In the LV area, several Pb values exceeded the PEL, many of them higher than the TEL, north of the highway between the towns of La Vega and SMF (**Table 1** & **Figure 2(d)**). According to the SQuiRTs table, these soils do not need intervention in relation to Lead (**Figure 3(d)**). As for the soils of the SFM province, they were higher than the TEL, except for some values that were below; one value was higher than PEL. Although in the SFM area the values slightly exceed the TEL, this area, like La Vega, needs some attention, to avoid reaching the PEL according to CEQGs-SQuiRTs. In the case of Ni, almost all the values exceeded

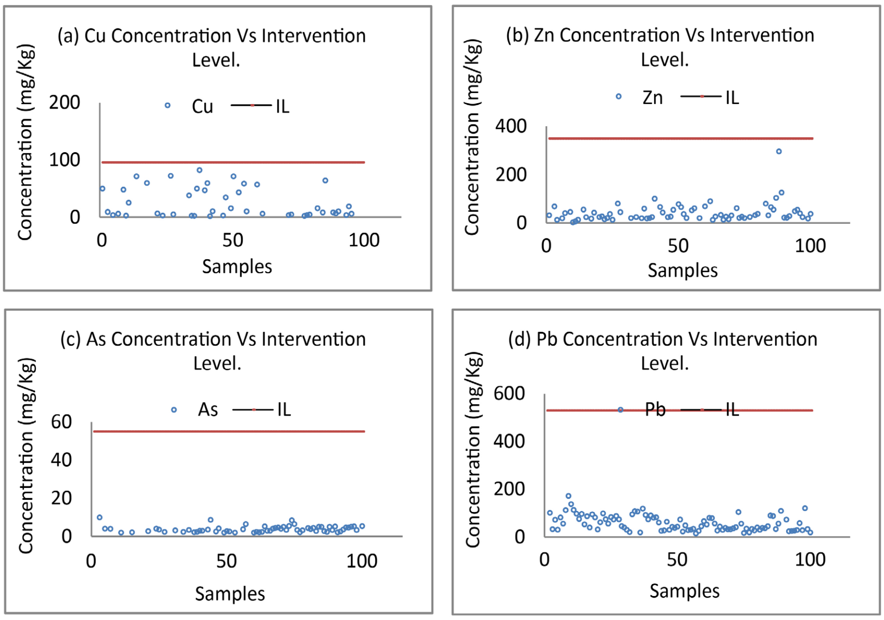

Figure 3. Distribution of Cu, Zn, As and Pb in the soils sampled in La Vega and San Francisco of Macorisversus their respective Intervention Level (NOAA-USEPA). Regarding Cu, Zn, As and Pb, the region does not need intervention measures.

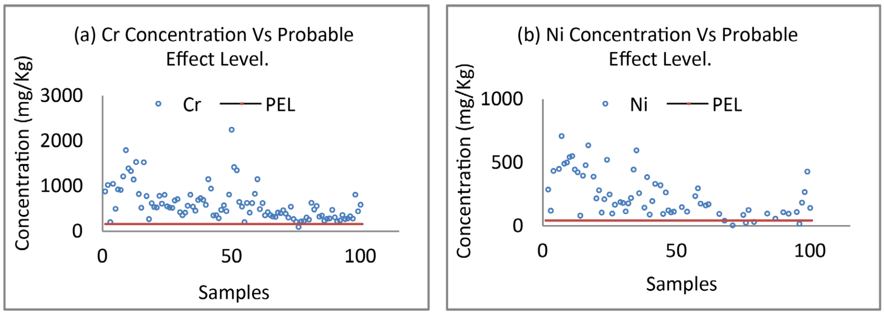

Figure 4. Distribution of Cr and Ni in the soils sampled in La Vega and San Francisco of Macorisversus their respective Probable Effect Level (NOAA-USEPA). The Cr and Ni values in both cases exceed the PEL.

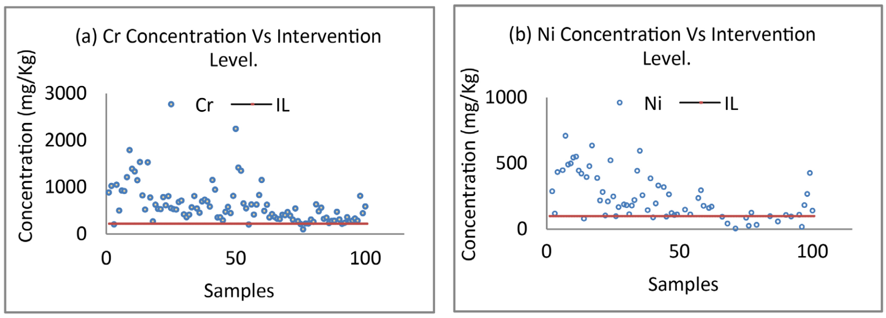

Figure 5. Distribution of Cr and Ni in the soils sampled in La Vega and San Francisco of Macorisversus their respective Intervention Level (NOAA-USEPA). The Cr and Ni values in both cases exceed the Intervention Level.

Table 1. Normal concentrations in soils, threshold effect levels, probable effects and intervention level according to the NOAA-USEPA SQuiRTs table and Canadian Sediment quality guidelines CSQGs (CCME, 2014). Right, averages concentrations in study zone. The average values of Hg and As correspond to some samples where levels higher than 2 mg/Kg are found.

Elements	Soil ($mg \cdot Kg^{-1}$)		Fresh Water Sediment ($mg \cdot Kg^{-1}$)		Marine Sediment ($mg \cdot Kg^{-1}$)		Concentration ($mg \cdot Kg^{-1}$)	
	NVS[1]	IL[4]	TEL[2]	PEL[3]	TEL[2]	PEL[3]	La Vega Mean	LV-SF Macoris Mean
As	5.20	55	5.90	17.00	7.20	41.6	3.8	3.8
Cr	37.00	220	37.30	90.00	52.30	160.0	770.5	351.4
Cu	17.00	96	35.70	197.00	18.70	108.0	31.9	11.9
Pb	16.00	530	35.00	91.30	30.20	112.0	17.1	45.9
Zn	48.00	350	123.00	315.00	124.00	271.0	38.5	50.8
Ni	13.00	100	18.00	36.00	15.90	42.8	293.4	111.7
Hg	0.06	10	0.17	0.49	0.13	0.7	5.0	3.9

[1]Normal Value in Soil; [2]Threshold Effect Level; [3]Probable Effect Level; [4]Intervention Level.

the PEL (Figure 4(b)) in the LV area; in this case we cannot consider it as contamination since it is to be expected because it is a region influenced by Nickel mining; only in some samples the levels were below the TEL. In the western part of the LV-SFM area the Ni exceeded the PEL; so is the PEL value in most samples. Further towards SFM the values do not reach the PEL values except for one sample. In this area the influence of Ni mining is minimal, as it is far away. Chromium and Nickel need intervention according SQuiRTs table (Figure 5(a) and Figure 5(b)); while Copper, Zinc, Arsenic, and Lead do not need it (Figures 3(a)-(d)). According to the distribution of heavy metals in LV, the Cr and Ni values were higher than in SFM (Figure 6(a) and Figure 6(b)); while Cu, Zn, and Pb (Figure 6(c), Figure 6(d) & Figure 7(b)) were found to have higher values in SFM than in LV. The distribution of As was similar in both areas (Figure 7(a)).

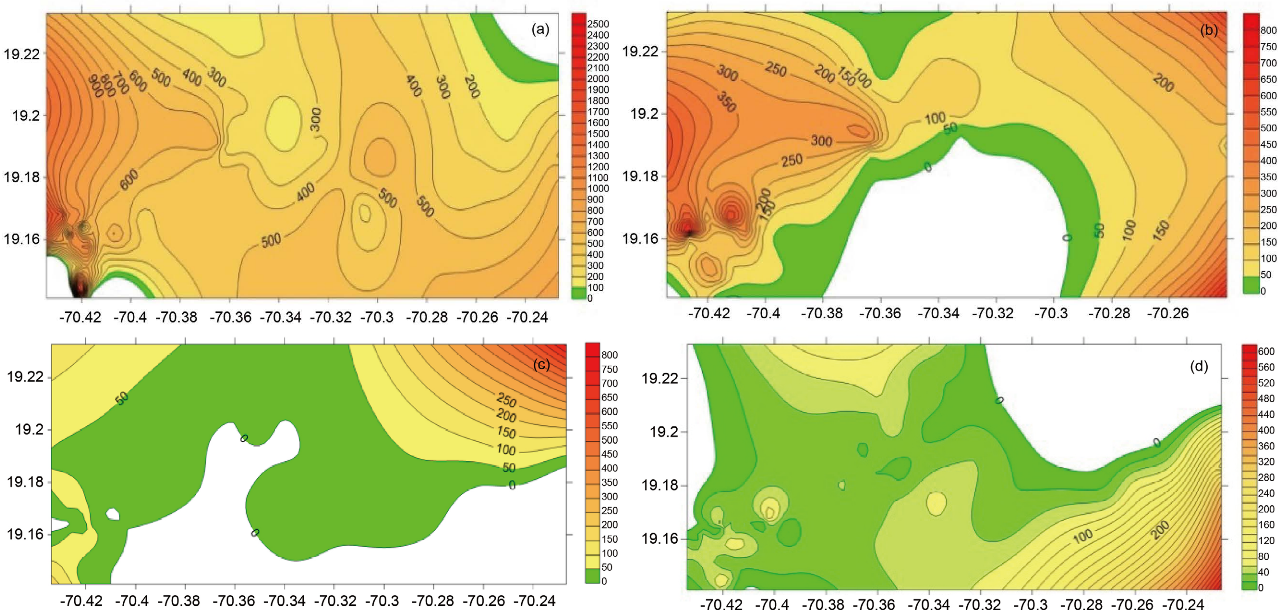

Figure 6. Comparative distribution of Cr (a), Ni (b), Cu (c) and Zn (d) in the La Vega (LV) and San Francisco de Macoris (SFM) regions. To the left of each graph corresponds to LV and to the right to SFM. The colors correspond to the normal ground level (green), threshold effect level (yellow) and probable effect level (red) of each element.

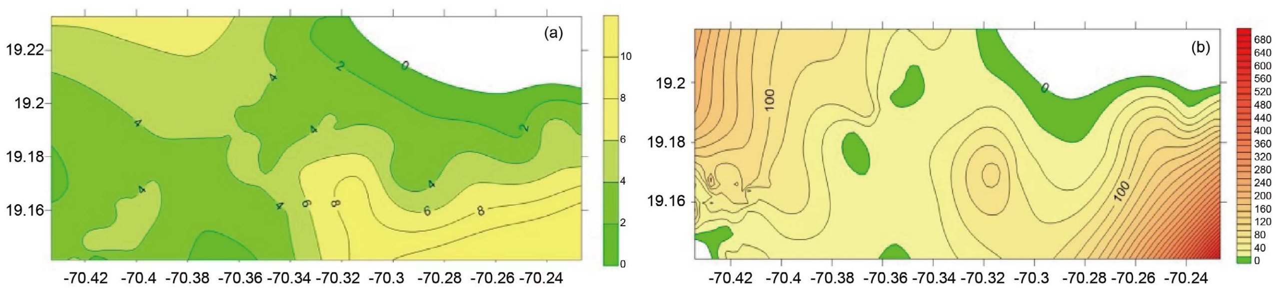

Figure 7. Comparative distribution of As (a) and Pb (b) in La Vega (LV) and San Francisco de Macoris (SFM) regions. To the left of each graph corresponds to LV and to the right to SFM. The colors correspond to the normal ground level (green), threshold effect level (yellow) and probable effect level (red) of each element.

5. Conclusion

The Cr and Ni levels in almost all the agricultural soil samples in the La Vega and San Francisco de Macorís area exceed the PEL values of the Canadian Agricultural Soil Quality Guide (CEQGs) and the Sediment and Soil Quality Guide of the United States of America USEPA-SQuiRTs-NOAA, so they are considered agricultural soils not suitable for growing crops that are bioaccumulators of these metals in their food product. The Pb in the majority of soil samples exceeded the TEL value and in the vicinity of the villages the PEL in agricultural soils, so it is necessary to consider these soils in cultivation that are bio-accumulators of lead in their food product. Elements As and Hg were found in a general sense below the respective PEL values. Zn and Cu in both areas only in one sample exceed the PEL value of the Zn, possibly due to specific anthropic activities. We consider these soils of good quality in relation to Zn and Cu. The high levels of Ni and Cr are associated with the fact that in the La Vega and Bonao zone there is a deposit of peridotite, a Ni as well as Cr forming spinel mineral. The heavy metals found in the study area were dragged from the mining area by the Camú and Jima Rivers and later deposited in the agricultural soils studied. Therefore, it is not recommended to carry out intervention measures.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Aiglsperger, T., Proenza, J.A., Zaccarini, F., Lewis, J. F., Garuti, G., Labrador, M. & Longo, F. (2015). Platinum Group Minerals (PGM) in the Falcondo Ni-Laterite Deposit, Loma Caribe peridotite (Dominican Republic). *Mineralium Deposita, 50,* 105-123. https://doi.org/10.1007/s00126-014-0520-9

Ali, M. S., Kim, G. D., Seo, H. W., Jung, E. Y., Kim, B. W., Yang H. S., & Joo, S. T. (2011). Possibility of Making Low-fat Sausages from Duck Meat with Addition of Rice Flour Department of Animal Science, Gyeongsang National University, Jinju, Gyeongnam 660-701, Korea. *Asian-Australasian Journal of Animal Sciences, 24,* 421-428. https://doi.org/10.5713/ajas.2011.10095

AqeelKamran, M., Syed, A., Musstjab Akber, S., Bibi, S., Xu, R., Hussain-Monis, M. F., Katsoyiannis, A., Bokhari, H., & Chaudhary, H. J. (2016). Bioaccumulation of Nickel by

E. sativa and Role of Plant Growth Promoting Rhizobacteria (PGPRs) under Nickel Stress. *Ecotoxicology and Environmental Safety, 126,* 256-263. https://doi.org/10.1016/j.ecoenv.2016.01.002

Arranz-González, J., & Alberruche, E. (2007). *Minería, Medio Ambiente y Gestión del Territorio*. Ricardo Castroviejo y José Antonio Espí (Ed.), Red DESIR-UPM-Programa ALFA.

Bravo-Covarrubias, A., Torres, E., Ayora, C., & Ramos-Arroyo, Y. R. (2020). Movilidad de arsénico en los sedimentos de una presa que recibe escurrimientos de minas epitermales. *Revista Internacional De Contaminación Ambiental, 36,* 797-811. https://doi.org/10.20937/RICA.53318

Canadian Council of Ministers of the Environment (CCME) (2014). *Canadian Environmental Quality Guidelines (CEQGs)*. Canadian Council of Ministers of the Environment.

Cordero, A. y Ramírez, G. F. (1979). Análisis y Comentario Acumulamiento de Cobre en los Suelos del Pacifico sur de Costa Rica y sus efectos detrimentales en la Agricultura. *Agronomia Costarricense, 3,* 63-78.

Delanoy, R., Espinosa, C., & Herrera, Y. (2022). Heavy Metals in the Northwest Agricultural Region Dominican Republic. *Journal of Geoscience and Environment Protection, 10,* 16-24. https://doi.org/10.4236/gep.2022.105002

Fernández-Ruiz, R. (2009). Fluorescencia de Rayos X por Reflexión Total (TXRF): Una gran desconocida. *Anales de Química, 106,* 5-12.

Freedman, B. (2018). Chapter 18. Toxic Elements. In *Environmental Science*. Dalhousie University Libraries Digital Editions. https://digitaleditions.library.dal.ca/environmentalscience/chapter/chapter-18-toxic-elements/

Fuentes-Hernández, M. V., Sanguinetti-Gamboa, O. A., & Rojas-De-Astudillo, L. L. (2019). Evaluación Del Riesgo Ambiental De Metales Pesados En Los Sedimentos Superficiales Del Saco Del Golfo De Cariaco. *Revista Internacional de Contaminación Ambiental, 35,* 101-114. https://doi.org/10.20937/RICA.2019.35.01.07 https://www.revistascca.unam.mx/rica/index.php/rica/article/view/RICA.2019.35.01.07

Gjoka, M., Kurant, M., Butts, C. T., & Markopoulou, A. (2010). Walking in Facebook: A Case Study of Unbiased Sampling of Osns. In *Proceedings IEEE INFOCOM* (pp. 1-9). Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/INFCOM.2010.5462078

Lewis, J. F, Draper, G., Proenz,a J. A., Espaillat, J., & Jiménez, J. (2006). Ophiolite-Related Ultramafic Rocks (Serpentinites) in the Caribbean Region: A Review of Their Occurrence, Composition, Origin, Emplacement and Nickel Laterite Soils. *Geologica Acta, 4,* 237-263.

Londoño-Franco, L. F., Londoño-Muñoz, P. T., & Muñoz-García, F. G. (2016). Los riesgos de los metales pesados en la salud humana y animal. *Biotecnología en el sector agropecuario y agroindustrial, 14,* 145-153.

Marchesi, C., Garrido, C. J., Proenza, J. A., Hidas, K., Varas-Reus, M. I., Butjosa, L., & Lewis, J. F. (2016). Geochemical Record of Subduction Initiation in the Sub-Arc Mantle: Insights from the Loma Caribe Peridotite (Dominican Republic). *Lithos, 252-253,* 1-15. https://doi.org/10.1016/j.lithos.2016.02.009

Marguí, E., Gonzalez, O., Hidalgo, M., Pardini, G., & Queralt, I. (2011). Aplicación de la técnica de espectrometría de fluorescencia de rayos-X en el estudio de la dispersión de metales en áreas mineras. *Boletín Geológico y Minero, 122,* 273-286.

Martínez-Alva, G., Gheno-Heredia, Y. A., Vieyra-Reyes, P., Martínez-Campos, A. R., Castillo-Cadena, J., López-Arriaga, J. A., Manzur-Quiroga, M. A., & Arteaga-Reyes, T. T. (2020). Geodisponibilidad de elementos potencialmente tóxicos en suelos agrícolas que representan riesgo para el ambiente y la salud de la población del Nevado de Toluca, México. *Revista Internacional De Contaminación Ambiental, 36,* 847-856. https://doi.org/10.20937/RICA.53614

McDonald, A. M., Proenza, J. A., Zaccarini, F., Rudashevsky, N. S., Cabri, L. J., Stanley, C. J., Rudashevsky, V. N., Melgarejo, J. C., Lewis J. F., Longo, F., & Bakker, R. J. (2010). Garutiite, (Ni, Fe, Ir), a New Hexagonal Polymorph of Native Ni from Loma Peguera, Dominican Republic. *European Journal of Mineralogy, 22,* 293-304. https://doi.org/10.1127/0935-1221/2010/0022-2007

Mesa-Pérez, M. A., Díaz-Rizo, O., Sánchez-Pérez, J. M., Baqué, D., & Tavella, M. (2015). Bioacumulaci ón de metales pesados en arroz cultivado bajo condiciones de contaminación en la subcuenca Mampostón. *Revista Ciencias Técnicas Agropecuarias, 24,* 25-30.

Pérez-Olvera, M. A., García-Mateos, R., Vázquez-Alarcón, A., Colinas-León, T., Pérez-Grajales, M., & Navarro-Garza, H. (2008). Concentración de Pb, Cd, Ni y Zn en Suelos contaminados y su transferencia a la pella de Brócoli. *Terra Latinoamericana, 26,* 215-225.

Prieto-Méndez, J., González-Ramírez, C. A., Román-Gutiérrez, A. D., & Prieto-García, F. (2009). Contaminación y Fitotoxicidad en plantas por metales pesados provenientes de suelos y agua. *Tropical and Subtropical Agroecosystems, 10,* 29-44.

Raju, L. K., Vishnuvardhan, V., Middepogu, A. R., & Damodhraram, T. (2016). Evaluation of Accumulated Heavy Metals in Soil and Plant Bodies of *Oryza sativa* L. and Triticumvulgare. *Innoriginal Originating Innovation, 3*.

Roca, M., & Bayon, A. (1981). *Determination of Copper in Geological Materials by X-Ray Fluorescence* (JEN--491). http://inis.iaea.org/search/search.aspx?orig_q=RN:39036509.

Romic, M., & Davor, R. (2003). Heavy Metals Distribution in Agricultural Topsoils in Urban Area. *Environmental Geology, 43,* 795-805. https://doi.org/10.1007/s00254-002-0694-9

Rudnick, R. L., & Gao, S. (2003). Composition of the Continental Crust. *Treatise on Geochemistry, 3,* 1-64. https://doi.org/10.1016/B0-08-043751-6/03016-4

Sepúlveda, B., Tapia, M., Tapia, P., Milla, F., & Pavez, O. (2020). Heavy Metals Bioabsorption and Soil Stabilization by *Sarcocornia neei* from experimental Soils Containing Mine Tailings. *Revista Internacional de Contaminación Ambiental, 36,* 567-575. https://doi.org/10.20937/RICA.53027 https://www.revistascca.unam.mx/rica/index.php/rica/article/view/RICA.53027

Shahbaz, A., Iqbal, M., Jabbar, A., Hussain, S., & Ibrahim, M. (2018). Assessment of Nickel Bioavailability through Chemical Extractants and Red Clover (*Trifoliumpratense* L.) in an Amended Soil: Related Changes in Various Parameters of Red Clover. *Ecotoxicology and Environmental Safety, 149,* 116-127. https://doi.org/10.1016/j.ecoenv.2017.11.022

Sibello-Hernández, R., Letizia-Cozzella, M., Mariani, M., Cogliati, N., Spezia, S., & Trivellone, E. (2014). Desarrollo de un método analítico para la caracterización isotópica de los suelos. *Revista Cubana de Química, XXVI,* 47-54. https://www.redalyc.org/articulo.oa?id=443543737007

Villanova-de-Benaven, C., Nieto, F., Viti, C., Proenza, J. A., Galí, S., & Roqué-Rosell, J. (2016). Ni-Phyllosilicates (Garnierites) from the Falcondo Ni-Laterite Deposit (Dominican Republic): Mineralogy, Nanotextures, and Formation Mechanisms by HRTEM and AEM. *American Mineralogist, 101,* 1460-1473. https://doi.org/10.2138/am-2016-5518

Vyzmalová, A., Laufer, F., Drábek, M., Stanley, C., Bakker, R. J., Bermejo, R., Garuti, G., Thalhammer, O., Proenza, J. A., & Longo, F. (2012). Zaccariniite, RhNiAs, a New Platinum-Group Mineral Species from Loma Peguera, Dominican Republic. *Canadian Mineralogist, 50,* 1321-1329. https://doi.org/10.3749/canmin.50.5.1321

Xuan, T., Nguyen, T., Amyo, T. M., & Labrecque, M. (2017). Differential Effects of Plant Root Systems on Nickel, Copper and Silver Bioavailability in Contaminated Soil. Chemosphere, 168, 131-138. https://doi.org/10.1016/j.chemosphere.2016.10.047