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# Evaluation of Potential Ecological Risk Index of Toxic Metals Contamination in the Soils

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# Introduction

- One of the most serious environmental issues facing the world today is soil contamination. The toxic contaminants in the soil spread to other parts of the ecosystem and pose a direct or indirect threat to human health.

- Industrial emissions, illegal dumping, municipal disposal of wastes, and the improper use of agrochemicals collectively contribute to the concentration and absorption of heavy toxic metals in the environment.

- Toxic metal contamination has been linked to serious health consequences in humans, including cardiac diseases, skeletal illnesses, infertility as well as neurological disorders.

- The technique for estimating the injury or damage from a possible health threat is referred to as risk assessment. In general, risk assessment is a scientific framework for environmental policy.

- The general objective of risk assessment is to pay attention to the contamination status of soil, air, water, or sediment, and to determine the potential negative effects of this amount of contaminants on organisms.

- It is possible to assess and analyze the contamination of areas in the soil using different indices, such as the Index of Contamination factor ($C_f$), Ecological risk factor ($E_r$) and Potential Ecological Risk Index ($RI$).

# Research Objectives

This study aims to:

(i) determine the concentrations of toxic metals, including arsenic (As), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) in the surface soil,

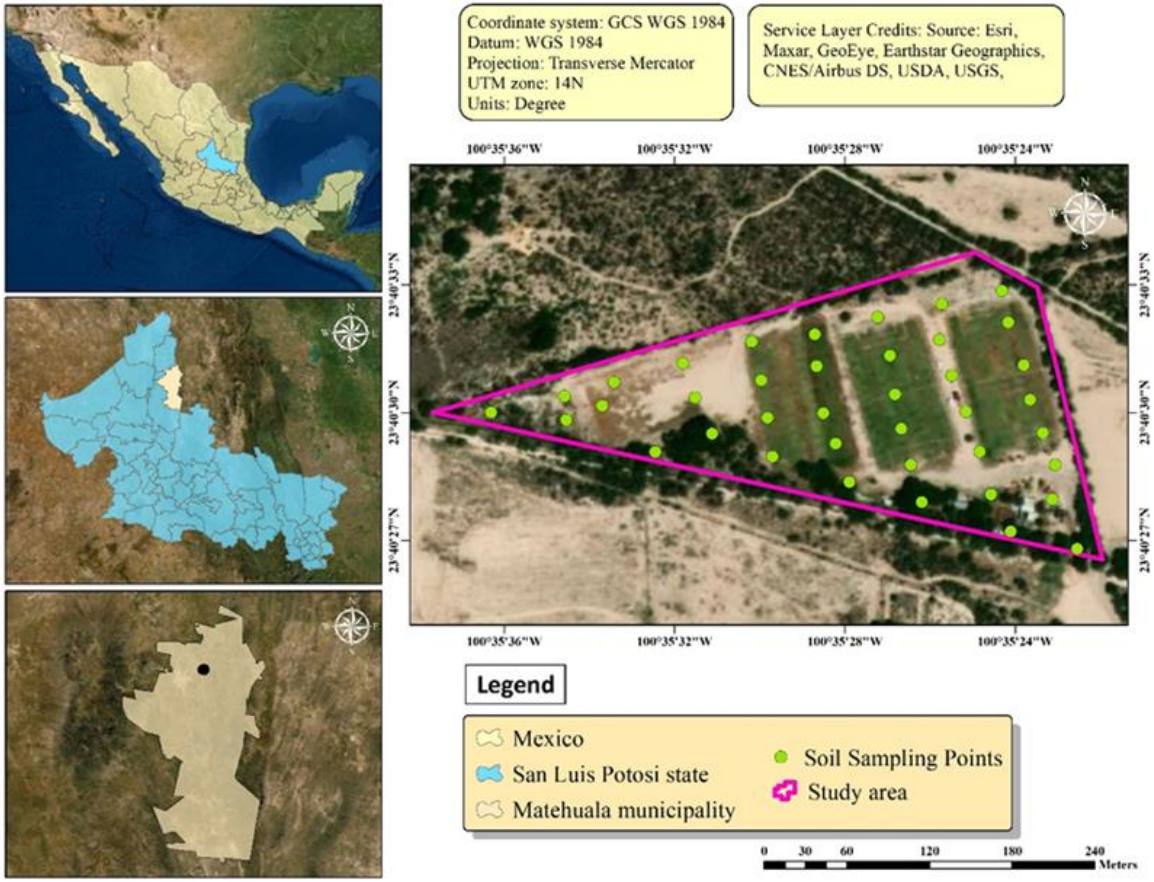
(ii) evaluate the status of contamination by using the contamination factor (Cf),

(iii) assess the ecological risk factor (Er), and

(iv) evaluate the potential ecological risks and spatial distributions of target toxic metals in the soil of the study area.

# Study Area

- Soil samples were collected from the fields close to an abandoned mining area surrounded by non-cultivated farmland in Cerrito Blanco, Matehuala municipality, San Luis Potosi, Mexico.
- The study area is Joya Verde soccer sports club, which comprises irrigated lands, including three half-hectare soccer grounds, and vegetative areas, known as non-irrigated lands, surrounding the soccer pitches.
- It has a total geographical area of around 4.84 hectares and is positioned within 23°40'30" N latitude and 100°35'27" W longitude.
- The types of soil in this area include Calcisol and Gypsisol, and the area receives limited precipitation, ranging from 300 to 500 mm per year.



# Materials and Methods

### *Soil Sampling and Chemical Analyses*

- A total of 39 surface soil samples were collected with an auger at a depth of 0–5 cm from the study area including soccer fields.
- A Garmin Etrex Personal navigator global positioning system receiver was used to geo-locate all the soil sampling locations.
- All soil samples were dried at room temperature and sieved for fractions less than 2 mm. In a beaker, 1.0 gm of soil was poured, followed by 10 mL of aqua regia (HNO3:HCl) with a ratio of 3:1.

### *Assessment of Soil Contamination Risk*

Contamination factor ($C_f$):

$$C_f = \frac{C_{metal}}{C_{background}}$$

Where, $C_{metal}$ denotes the measured metal concentration of the soil sample, $C_{background}$ is the background reference concentration values of the individual metals.

# Materials and Methods

## *Assessment of Soil Contamination Risk*

Ecological risk factor ($E_r$):

$$E_r = T_r \times C_f$$

Where, $T_r$ is the toxic response factor values for each different metal, which are described in the below table, and $C_f$ is the contamination factor.

Toxic-response factor values of toxic metals by Hakanson.

| Metals | As | Cu | Ni | Pb | Zn |
|---|---|---|---|---|---|
| Toxic-response factor | 10 | 5 | 5 | 5 | 1 |

Potential Ecological Risk Index ($RI$):

$$RI = \sum E_r$$

Where $E_r$ is the ecological risk factor of a toxic metal element in each soil sampling point.

# Materials and Methods

Contamination indices classification for the soil.

| Index | Category | Description |
|---|---|---|
| Contamination factor ($C_f$) | $C_f < 1$ | Low contamination |
| | $1 \leq C_f < 2$ | Low to moderate contamination |
| | $2 \leq C_f < 3$ | Moderate contamination |
| | $3 \leq C_f < 4$ | Moderate to high contamination |
| | $4 \leq C_f < 5$ | High contamination |
| | $5 \leq C_f < 6$ | High to very high contamination |
| | $C_f \geq 6$ | Extreme contamination |
| Ecological risk factor ($E_r$) | $E_r < 40$ | Low risk |
| | $40 \leq E_r < 80$ | Moderate risk |
| | $80 \leq E_r < 160$ | Considerable risk |
| | $160 \leq E_r < 320$ | High risk |
| | $E_r \geq 320$ | Very high risk |
| Potential Ecological Risk Index ($RI$) | $RI < 150$ | Low risk |
| | $150 \leq RI < 300$ | Moderate risk |
| | $300 \leq RI < 600$ | Considerable risk |
| | $RI \geq 600$ | High risk |

# Results

Descriptive statistics for selected toxic metals of soil samples.

| | Arsenic (As) | Copper (Cu) | Nickel (Ni) | Lead (Pb) | Zinc (Zn) |
|---|---|---|---|---|---|
| Mean (Measured) | 119.44 | 20.65 | 3.20 | 36.95 | 58.93 |
| Standard Error | 17.54 | 1.56 | 0.30 | 3.97 | 5.56 |
| Median | 90.51 | 18.10 | 3.07 | 30.86 | 54.57 |
| Standard Deviation | 109.54 | 9.75 | 1.87 | 24.79 | 34.71 |
| Kurtosis | 8.37 | 3.63 | 0.93 | 5.73 | 15.38 |
| Skewness | 2.43 | 1.68 | 0.93 | 2.12 | 3.27 |
| Range | 578.17 | 47.85 | 8.13 | 126.30 | 209.81 |
| Minimum | 13.14 | 7.88 | 0.24 | 8.99 | 20.53 |
| Maximum | 591.31 | 55.73 | 8.37 | 135.29 | 230.34 |
| Sum | 4658.01 | 805.17 | 124.90 | 1440.99 | 2298.24 |
| Coefficient of variation (CV) (%) | 91.71 | 47.22 | 58.32 | 67.10 | 58.90 |
| Samples | 39 | 39 | 39 | 39 | 39 |
| Confidence Level (95.0%) | 35.51 | 3.16 | 0.61 | 8.04 | 11.25 |
| Permissible Limits (mg/kg) | 10 | 36 | 35 | 85 | 50 |

# Results

- The principal component analysis (PCA) revealed the potential relationships between the various environmental conditions and the identified toxic metals.
- PCA with VARIMAX normalized rotation was used to determine the source of toxic metals in this study soils since it is an efficient technique for evaluating toxic metals source identification.
- To determine the linear correlation between two metal elements, Pearson's correlation coefficient was performed.

| Elements | Principal components | | Communalities |
|---|---|---|---|
| | PC1 | PC2 | |
| **As** | 0.119 | -0.838 | 0.717 |
| **Cu** | **0.981** | 0.067 | 0.966 |
| **Ni** | 0.235 | **0.816** | 0.722 |
| **Pb** | **0.819** | **0.342** | 0.788 |
| **Zn** | **0.905** | -0.164 | 0.846 |
| *Eigen value* | 2.522 | 1.517 | |
| *% of variance* | 50.431 | 30.347 | |
| *Cumulative %* | 50.431 | 80.778 | |

| Metals | As | Cu | Ni | Pb | Zn |
|---|---|---|---|---|---|
| As | 1 | | | | |
| Cu | 0.029 | 1 | | | |
| Ni | -0.408** | 0.264 | 1 | | |
| Pb | -0.137 | 0.795** | 0.410** | 1 | |
| Zn | 0.130 | 0.878** | 0.054 | 0.537** | 1 |

**$p<0.01$

# Results

***Assessment of Contamination and Environmental Risk***

- The assessment of $C_f$ values represented that As was the major contaminant in the study soil because the mean concentration level of As represents extreme contamination level ($C_f$ >6).
- The $C_f$ result showed that 26 sampled locations were in extreme contamination level ($C_f$ >6), two in high to very high contamination, three in high contamination, two in moderate to high contamination, two in moderate contamination, and four in low to moderate contamination.
- The assessment of $E_r$ values also represented that As was the main contaminant in the study soil because the mean concentration level of As was at a considerable risk level ($80 \leq E_r < 160$).

# Results

*Assessment of Contamination and Environmental Risk*

- The whole study area including the three soccer grounds can be categorized as having a moderate ecological risk level.
- Most of the locations of this study area can be classified as low ecological risk level ($RI < 150$).

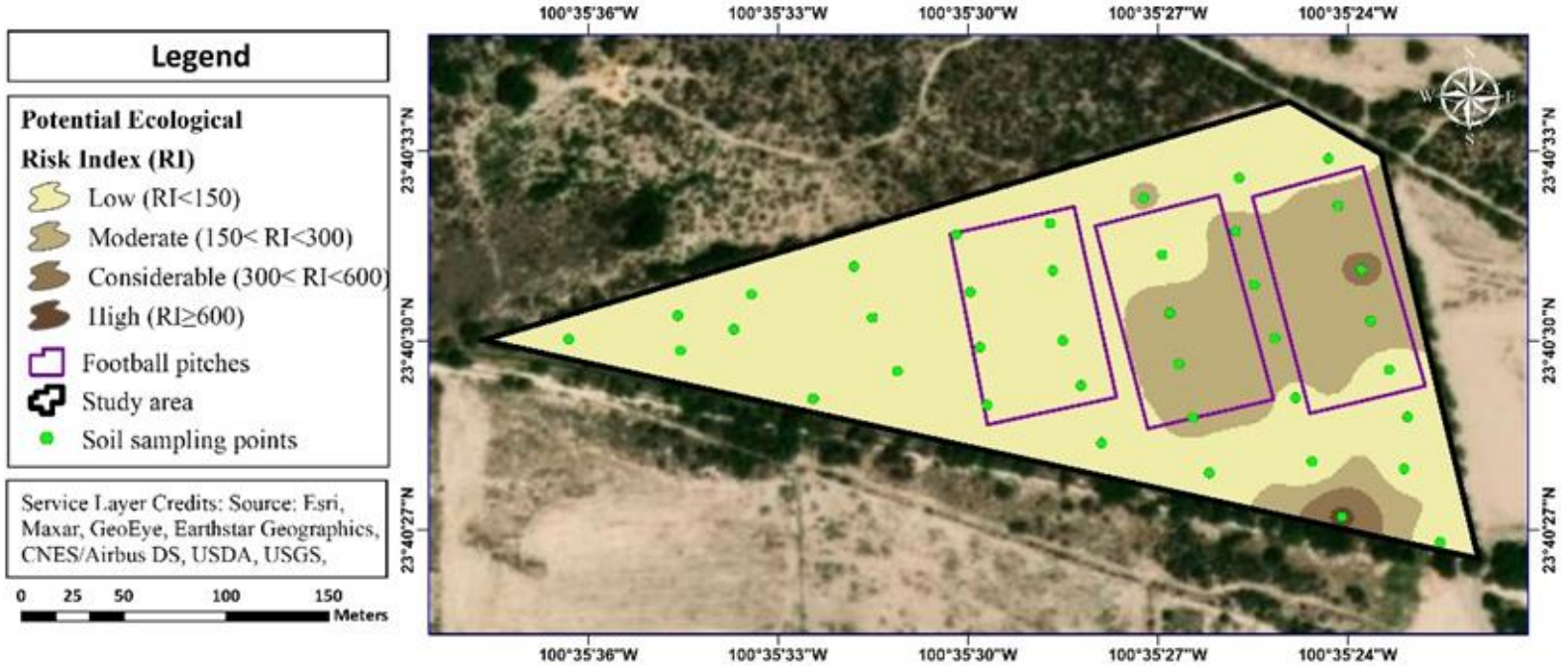
| Heavy metals | As | | Cu | | Ni | | Pb | | Zn | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Contamination indices | $C_f$ | $E_r$ | $C_f$ | $E_r$ | $C_f$ | $E_r$ | $C_f$ | $E_r$ | $C_f$ | $E_r$ | *RI* |
| **Mean ($\bar{x}$)** | 11.94 | 119.44 | 0.57 | 2.87 | 0.09 | 0.46 | 0.43 | 2.17 | 1.18 | 1.18 | 126.11 |
| **Median (med)** | 9.05 | 90.51 | 0.50 | 2.51 | 0.09 | 0.44 | 0.36 | 1.82 | 1.09 | 1.09 | 100.34 |
| **Minimum (min)** | 1.31 | 13.14 | 0.22 | 1.09 | 0.01 | 0.03 | 0.11 | 0.53 | 0.41 | 0.41 | 17.32 |
| **Maximum (max)** | 59.13 | 591.31 | 1.55 | 7.74 | 0.24 | 1.20 | 1.59 | 7.96 | 4.61 | 4.61 | 601.34 |
| **Standard deviation (SD)** | 10.95 | 109.54 | 0.27 | 1.35 | 0.05 | 0.27 | 0.29 | 1.46 | 0.69 | 0.69 | 109.41 |

- For the spatial distribution, the inverse distance weighting (IDW) interpolation technique was applied to evaluate the distribution of potential ecological risk levels for toxic metals in the surface soil, because it is a suitable approach for interpolating regularly spaced specific sampling point data.

# Results

*Assessment of Contamination and Environmental Risk*

- According to the results of the potential ecological risk level distribution pattern, 73.52 per cent of the soils were having low ecological risk level, 24.80 per cent was in the moderate ecological risk level, 1.50 per cent of soils had considerable ecological risk level, while 0.19 per cent of soils was in the high ecological risk level.
- Furthermore, most areas are in the low ecological risk level zone, but specific areas of soccer grounds have moderate ecological risk levels because of the persistent use of As-contaminated irrigated water.



# Conclusions

- The primary metal contaminants were arsenic (As) and zinc (Zn), with amounts in most of the soil samples above the toxic metal background reference value.
- The $C_f$ values revealed that the soil had a low range of contamination with Cu, Ni, Pb, a low to moderate range of contamination with Zn, and an extreme level of contamination with As.
- $E_r$ demonstrated that the soil had a low risk of contamination with Cu, Ni, Pb, and Zn, but a very high risk of contamination with As.
- According to the level of potential ecological risk index (*RI*), arsenic (As) poses the highest risk of toxic metals, while the other metals have a low-risk level.
- The surrounding areas with intensive industrial operations, past mining activities, and the growth of urban populations were often characterised by a moderate and considerable potential ecological risk.
- The outcomes of this work provide a better knowledge of toxic metal enrichment and the risk of soil used for sports purposes, which is a significant issue for human health.

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