

INFORME SECRETARIAL

FECHA: 06/06/2022

DESTINATARIO: MINISTERIO DE LA PRESEIDENCIA

NOTA DE CONSULTA: DM-0932-2022

Asunto: Notificación a Nota de Respuesta

Por este medio se deja constancia que, el día 31 de mayo del presente año, se remite nota DM-0932-2022, al Ministerio de la Presidencia, donde se da respueata a la consulta de los trabajadores de la comunidad de San Francisco provincia de Veraguas, quienes manifiestan su disconformidad por la no aprobación de la Mina el Remance.

Sin otro particular,

Atentamente,


Tatiana I. Moreno Sousa
Secretaria Ejecutiva

Panamá, 24 de mayo de 2022
DM-0932-2022

Licenciado
LUIS ÁBREGO
Secretario Ejecutivo
MINISTERIO DE LA PRESIDENCIA
E. S. D.



**** MINISTERIO DE LA PRESIDENCIA
Código: MIPRE-2022-0020364
Contraseña consulta web: 584DE335
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Telef.: 527-9600

Respetado Licenciado Ábrego:

En atención a la Nota MIPRE-2022-0016357, recibida en nuestro despacho el 27 de abril de 2022, mediante la cual remiten nota enviada al Excelentísimo Señor Presidente Laurentino Cortizo Cohen, por los trabajadores de la comunidad de San Francisco provincia de Veraguas, quienes manifiestan su disconformidad por la no aprobación de la Mina Remance.

Sobre el particular, le indicamos que, el Estudio de Impacto Ambiental, categoría III, del proyecto "GREENFIELD MINING", cuyo promotor es "GREENFIELD RESOURCES, INC", ha sido rechazado por medio de la Resolución DEIA-IA-RECH-003-2022, de 26 de abril de 2022 que formaliza la decisión que culmina el procedimiento administrativo de evaluación; y actualmente se encuentra en espera de su debida notificación por parte del Promotor.

Sin otro particular, nos suscribimos.

Atentamente


MILCIADES CONCEPCIÓN
Ministro de Ambiente



MC/DDE/kc/es/ab/am

Albrook, Calle Broberg, Edificio 804
República de Panama
Tel.: (507) 500-0855
www.miambiente.gob.pa

Fecha : 20/05/2022

Para : Secretaría General

De: Ing. Domiluis Domínguez E

Pláceme atender su petición

De acuerdo

☐ URGENTE

☐ Dar su aprobación

☐ Resolver

☐ Procede

☐ Dar su Opinión

☐ Informarse

☐ Revisar

☐ Discutir conmigo

☒ Encargarse

☐ Devolver

☐ Dar Instrucciones

☐ Investigar

☐ Archivar

Se remite nota DM-0932-2022, dirigida al Licenciado Luis Ábrego
Secretario Ejecutivo del Ministerio de la Presidencia, para su
revisión y firma del Sr. Ministro.

Sin otro partiular,

Atentamente,

Domiluis Domínguez E.

Director de Evaluación



Fecha: 10/05/2022.

Para: Analitia

De: ING. DOMILUIS DOMÍNGUEZ E.

Pláceme atender su petición

De acuerdo

☐ URGENTE

- | | | |
|--|-------------------------------------|-----------------------------------|
| ☐ Dar su aprobación | ☐ Resolver | ☐ Procede |
| ☐ Dar su Opinión | ☐ Informarse | ☐ Revisar |
| ☐ Discutir conmigo | ☐ Encargarse | ☐ Devolver |
| ☐ Dar Instrucciones | ☐ Investigar | ☐ Archivar |

Nota dirigida al Sr. Presidente de la
República, por debajo de la Comandante
de San Francisco - Veraguas

10/5/22

114
A.M./A.B./E.S
11/5/22


REPÚBLICA DE PANAMÁ
GOBIERNO NACIONAL

MINISTERIO DE
AMBIENTE

HOJA DE
TRAMITE

Fecha : 9 de mayo de 2022

Para : Despacho del Ministro De: Secretaría General

Pláceme atender su petición De acuerdo ☐ URGENTE

☐ Dar su aprobación

☐ Resolver

☐ Procede

☐ Dar su Opinión

☐ Informarse

☐ Revisar

☐ Discutir conmigo

☐ Encargarse

☐ Devolver

☐ Dar Instrucciones

☐ Investigar

☐ Archivar

Remitimos Nota MIPRE-2022-0016357 del Ministerio de la Presidencia, suscribe el Secretario Ejecutivo, Luis Abrego, em ocasión de hacer llegar nota dirigida al Sr. Presidente de la República, por los trabajadores de la comunidad de San Francisco, Veraguas.

Adjunto: lo indicado

AGA/gd

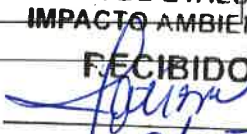



REPÚBLICA DE PANAMÁ
GOBIERNO NACIONAL

MINISTERIO DE
AMBIENTE

DIRECCIÓN DE EVALUACIÓN DE
IMPACTO AMBIENTAL

RECIBIDO

Por: 

Fecha: 10/05/2020

Hora: 12:46 pm

NOTA MIPRE-2022-0016357

4 de mayo de 2022

Señor Ministro:

Le remito para su evaluación, nota enviada al Excelentísimo Señor Presidente, Laurentino Cortizo Cohen, por los trabajadores de la comunidad de San Francisco, provincia de Veraguas, quien manifiestan su disconformidad por la no aprobación de la Mina Romance.

Con muestra de alta estima y respeto.

Atentamente,


LUIS ÁBREGO
Secretario Ejecutivo de Presidencia

Su Excelencia
Milciades Concepción
Ministro
Ministerio de Ambiente
Ciudad. -

/mg.-

 REPÚBLICA DE PANAMÁ GOBIERNO NACIONAL	MINISTERIO DE AMBIENTE
DIRECCIÓN DE EVALUACIÓN DE IMPACTO AMBIENTAL	
RECIBIDO	
Por:	
Fecha:	10/05/2022
Hora:	12:45 pm


2022 MAY 6 1:30PM
MIN. DE AMBIENTE

SECRETARIA GENERAL

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Telef.: 527-9600

112

San Francisco, 4 de abril de 2022

✓ M.G.
Laurentino Cortizo C.
Presidente de la República de Panamá
E. S. D.

Lic: Milciades Concepción
Ministro de Ambiente

65849715
arilis

Señor: Presidente:

Reciba usted un cordial saludo
de los trabajadores de la comunidad de San
Francisco (Veracruz).

Los señores (11) comunidades que participamos
del Foro Público, que la empresa de la Hina
Romance, hizo el día 28 de marzo en la casa
Comunal de La Gorda y los de las comunidades
llegamos temprano y los encargados del foro nos
otorgaron y tuvieron el tiempo para hablar con
nosotros y decirnos que es el proyecto.

Ya no somos ignorante, como los grupos
de afuera creen que somos ignorantes y sabemos
cuando nos mienten y también cuando nos
dicen la verdad, los que temprano hacíamos
nuestras preguntas y nos respondían cada
una de ellas, aun sabiendo que la reunión

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no había comenzado, ya los de las comunidades estaban allí, con ganas de conocer más del proyecto, porque la mina ya la conocemos, allí vivimos allí nacimos, y nuestros padres y todos nosotros crecimos allí.

No pueden venir a decirnos que la gente murió de cáncer, que la gente quedó ciega y todos esas mentiras, que en esta comunidad nadie a muerto de cáncer o se han quedado ciegos por culpa de la mina, para que luego personas que no viven aquí y nos quieran decir las que ellos no vivieron, por que esos grupos no son de nuestras comunidades. Pero vienen a tratarnos de ignorantes, y amonazarnos para que no digamos nada sin decirnos hablar cuando ellos viven, porque nosotros cuando comenzamos al Foro no hablamos con miedo a que ellos, a esos grupos ambientalista de maestros y de afuera que solo saben amonazar y callarnos para que solo ellos puedan hablar.

Nosotros los que vivemos aquí en estas comunidades de San Francisco, si queremos La Mina El Romance. Queremos volver a vivir el desarrollo en nuestras comunidades como lo hicieron nuestros padres, pero ahora exigiéndole a la empresa que cumpla con

hacer los casos bien. Ya sabemos que no son los mismos peruanos que se fueron y queremos que nos tomen en cuenta por que los gobiernos anteriores no nos tomaron en cuenta y por eso nuestros niños tienen que ir descalzos a la escuela por que no tienen zapatos, o por que si los tienen se los dan con las piedras, la polvareda y el latigazo en el cuerpo.

Son que abajo firmamos esta nota que somos moradores y residentes del distrito de San Francisco y especialmente de las comunidades de:

La Gorda, San Juan, Los Hermanos, La Hina Naranjal, La Utría, La Honda, Los Pintos, El Camarito, La Cuenta. Hemos visto como el 28 de marzo, grupos de afuera que no conocen nuestra necesidad y nuestras ganas de salir adelante, vienen en forma agresiva a meternos en la cabeza que todo proyecto que se quiera hacer en nuestra comunidad es mala, dañina que nos quieren quitar las tierras, entre cosas mas que ya sabemos que son puras mentiras, y muchas veces esta personas u organizaciones solo se acuerdan de nosotros cuando necesitan curar gallos y que quitamos cosas que ellos no se atreven a decir a los gobiernos.

No queremos ser mas usados de esa forma.

Señor Presidente y señor Ministro nosotros que si somos de la Comunidad.

Si Queremos La Mina El Romance

Saludos

Gracias

Madina Gonzales 9-760-663

Bernado Pinto 9-713-2231

Maria Rodriguez 9-702-557

Y. P. V. 9-123-543

Archiroy 9-754-415

Angelica Rodriguez 9-763-2460

Davis R. Nuñez M. 9-701-1079

9-755-945

La Mina

- maria mercedes Hernández R. 9-709-2391

- Amado Pinto Rodriguez 9-764-2076

Adon Rodriguez 9-218 640

Maria Dolores Pinto Rodriguez 9-769-146.

Disenio Rodriguez C. 9-133-692

Francisca Hernández H. 9-741-2351

maria De Jesus Hernández 9-755-713

natalia Rodriguez 9-188-804

marilyn mendoza 9-766-56

maria alba mendoza 9-746-1482

Angélica Pinto González 9-756-369.

- Esperanza de Hernandez 9-710-823

- Susana Concepción Hernández # 9-149-151

- Bimaldina Hernández 9-754-32

La Mina

Secundino Hernandez 9-211-570

- Jesus Concepcion 9-735-2013

- Marco Hernandez 9-753128

- Victor Hernandez 9-728-1463

- Melanio Hernandez 9-738-2343

- Ricardo Hernandez 9-737-1000

- Jose Mendoza 97662286

- Eric Amundaga 9-754-31

- 9173248 Apuricio Mendoza

- MAXIMO HERNANDEZ 9-701501

- Marcos Hernandez G - 9-136-470

- Dorot Concepcion 9-130-28

- Hector Hernandez 9-763-729

- Justo Hernandez 9-128-25

fa mina

- maria marco Hernández mendosa H 9-123-2591

- Juana Bautista Hernandez Hernandez 9-750-10-85

- Elices Hernandez

9-751-1016

- Edm' Dolores Camarena

9-219-170

- Luchas H. C. H. C.

9-1939

Los Pintos

- Cecilia Hernandez: 9-721-635
- Clemente Hernandez 9-728-891
- Jean Carlos Hernandez 9-750-2960
- Eulio Pinto H . 9-726-925
- Pablo Pinto 9-731-170
- Pedro Hernandez J 9-185-66
- Octavia Hernández Hernández 9-757-67
- Visitación Pinto Gonzalez 9-727-679
- Angélica Hernández 9-716-1626
- Maria E Hernandez 9-745-1953
- Maria Enobeba Pardo 9-762 1990
- Alejandro Rodriguez - 9-101-494
- Roberto Pinto. A 9-737-1494
- Tomás Pinto C. 9-115-1702

Los Pinto

- Maria L. Pinto C. 9-763-1085

- Agustina Hernandez 9-127-912

- Ana Rosa Hernandez 9-764-1535

- maria maribel pinto 9-746-2013

- Lourdes Hernandez 9-744-2430

- maria C. pinto Gomez 9-738-605

- Lucila Gonzales 9-160-324

- Nieves Pinto 9-102227

Comunidad La Gorda

- Kevin Mandoza 9-761-2300
- Pastor Concepcion 9-153 553
- Sotero Mandoza Cruz 9-153 548
- Osa Mandoza 9-745 1958
- Camilo Cruz 9-203 92
- ELADIER MESA 9-768-239
- Eda 9-762-1672
- Feliciano Hernandez 9-149-168
- Santo Pardo 9-221-1370
- Andres Pinto H 9-732-924
- Jorge Luis Hernandez H. 9-702-1500
- Juan Hernandez 9-749 -1129

Comunidad La Gorda.

Hernan Acán Hernandez 9-744-328

Alina Hde Hernandez 9-708-1004

Tomasa Hernandez 9-202-478

Comunidad Los Mesillas - La Gorda

- Luis Hernández 9-760-2379

- Alcira Hernández Mesa 9-700-2017

- Regulo Hernandez P 9-121-1452

- Francisco Hernandez = 9-755-714

- Enrique mesa H 9-124-2420

- Joaquina Hernández 9-703-234

- María Hernández 9-760-1146

- Casimira Conception 9-70-1766

- Angelica Hernandez 9-762-1135

- Maritza I. Mesa 9-101-1668

Comunicado El palmarito

Ela Hernández H 9-721-575

Demetria Hernández 9-101-1838

Mauricio Hernández 9-198-5

Juana pardo 9102375

Balbino Cruz 9-76-309

Micaela Cruz 9-728-1467

Babrio Concepción 9734-2303

Rubila Cruz 9-741-2200

Alijandra Recheque 9-201-77

José A pardo H 8-720-563

José C Daniel Cruz 9-755-419

Guilia Mandara e 916-674

Donato Antonio Benab 9-741-1675

Malinys Mandoza Mandoza 9-748-2459

BMC

9.128.64

Comunidad El Palmarito

- Pedro Pablo Hernández H 9-713 2321

- Justino Hernández 9-700-1693

- Isidro Hernández H 9-221-1065-

Comunidad La Peña Los Hernandez

- Maria Hernandez

- Maria Sofia Cruz

- Seresin Meris. 9,7090996

- Erik Hernandez 9-115-1660

- maria Dolores Hernandez 9.710-1764

- marcos Hernandez 9.741.2352

- Clementina H. 9.719-686

- Calista Pinto H 9-744-134

- Agustín Hernandez 9-747-1505

- Ernesto Hernandez 9-728-619

- Phil 9-743 994

- Damaris Hernandez gajal 9-199-244

- Eusebio Hernandez G. 9728-396

Comunidad Naranja.

- Eduardo Concepción 9-218-662

- Jorge R. González C. 9-761-427

- Cristino González 9-151-87

- Cristino González 9-744-293

- Carlos González 9-748-721

- Pastora Concepción H 9-220-1021

- Yareth González 9-758-2423

- Laurianis González 9-741-1994

- Julian González 9-763-2350

Comunidad Los Hernandez

- Cirilo Hernandez 9-218-590
- Iris Rodríguez 9-739-2239
- Yatzury Rodríguez 9-759-1089
- Rufino Hernandez C. - 9-75-158
- Carmen Rodríguez H 9-743-828
- Leonor Hernández Gómez 9-716-1636
- Leonardo Hernández P. 9-760-2033
- Anayansi Hernández P. 9-757-523
- Maria Jesus Porras 9-718-892
- Leonidas de Hernandez 9-133-711
- Verancio Hernandez Rodriguez 9-735-1780

Comunidad La Honda

Listado de Personal

1 Franklin Zambrano 9-705-2484

Isi Rodriguez 9-740-999

Don P Santana 9-719-715

Pablo Santana 9-151-871

Ydell Zamora N 9-745-1735

Maria Lujada 9-101-1922

Guillermo Zambrano 9-218-873

Rafael Zambrano 9-102-71

Comunidad La Honda

Teodoro Santana 9-739-1366

Teodoro Santana C. 9-100-1903

Aguilero Concepción B. C. 9-121-1450

Maritza L. Concepción R. C. 9-748-561

Viviana Zambrano 9-102-83

Eli A. Santana 9-728-644

Dominga Santana 9-722-992

Eva Maria Zambrano 9-139-1145

Yarexel Puga Santana 9-751-1007

Una Rodríguez 9-761-2389

Eduar Zambrano 9-753-1400

Andrés Rodríguez 9-753-1010

Vicente Rodríguez R. 9-718-659

Yolanda Bonilla 9-739-2299

Comunidad La Ufria

- Severiano Hernandez R 9-105-171
- Jose Angel Hernandez 9-218-678
- Jesus gaud Hernandez P 9736 1225
- Orel Hernandez 9-713 2222
- Leonica Hernandez 9.733.2372
- Juana Pinto de H 9.132.227
- Domingo Rodriguez H. 9-723-2330.
- ~~Yarel Pardo~~ 9-759-779
- Di
- Irineeth R. Hernandez H 8-950-1000
- Bernada Hernandez 9-736-836
- Luvia del C. Hernandez B. 9.747.279
- Oscar A. Gonzalez P. 9-742-1866
- Juana Hernandez 91001895
- Tomasa Pardo de Hernandez 9-710-2401

Comunidad Los Guces.

Lorenzo Cruz 9.709.323

REPÚBLICA DE PANAMÁ
MINISTERIO DE AMBIENTE
DIRECCIÓN REGIONAL DE VERAGUAS
Central Telefónica: 500 – 0734 (Ext. 6251)

Santiago, 22 de Abril del 2022
DRVE/ 0355 /2022

Ingeniero
DOMILUIS DOMÍNGUEZ
Director de Evaluación de Impacto Ambiental
Ministerio de Ambiente
En su despacho

Respetado Ingeniero Domínguez:

Remitimos informe **DRVE- No. 001- 2022** fechado del 05 de abril del corriente, respecto a la realización del Foro Público correspondiente al Estudio de Impacto Ambiental Categoría III titulado **“GREENFIELD MINING”** promovido Greenfield Resources Inc., actividad desarrollada en la comunidad de Piedras Gordas, Corregimiento de Remance, Distrito de San Francisco, Provincia de Veraguas.

Se adjunta: Informe en Original.

Atentamente,



ING. OCTAVIO NUÑEZ
Director Regional Encargado
Dirección Regional MiAMBIENTE/Veraguas.



/JF/YPalacios/

c.c. Archivo
c.c. Expediente

REPÚBLICA DE PANAMÁ		MINISTERIO DE AMBIENTE	
DIRECCIÓN DE EVALUACIÓN DE IMPACTO AMBIENTAL			
RECIBIDO			
Por:	Sanyris		
Fecha:	28/4/2022		
Hora:	10:39am		

MINISTERIO DE AMBIENTE
 DIRECCION REGIONAL DE VERAGUAS
 SECCIÓN DE EVALUACIÓN DE IMPACTO AMBIENTAL

INFORME DE FORO PUBLICO DRVE-No. 001-2022

I. DATOS GENERALES

PROYECTO:	GREENFIELD MINING	
PROMOTOR:	GREENFIELD RESOURCES INC	
CATEGORÍA:	III	
FECHA DE FORO PUBLICO	LUNES 28 DE MARZO DE 2021	
LUGAR DEL FORO PUBLICO 1	CASA COMUNAL DE LA COMUNIDAD DE LA GORDA EN EL CORREGIMIENTO DE REMANCE, DISTRITO DE SAN FRANCISCO, PROVINCIA DE VERAGUAS.	
FECHA DE INFORME:	5 DE ABRIL DE 2021	
EXPEDIENTE DEIA:	DEIA-III- M -002-2022	
EXPOSITORES:	PAMELA RÍOS MEJIA	CONSULTORA
	RODERICK GUTIERREZ	CONSULTOR

II. PREVIA DEL FORO PUBLICO:

El día 16 de marzo del 2022, se recibe en la Dirección de Evaluación de Impacto Ambiental del Ministerio del Ambiente-Panamá, el Memorando-DEEIA-0142-1503-2021 del 15 de marzo de 2022; a través del cual la Dirección de Evaluación y Ordenamiento Ambiental del Ministerio de Ambiente, envía propuesta de la programación de la fecha, hora y lugares del Foro Público al Estudio de Impacto Ambiental, categoría III, correspondiente al proyecto **GREENFIELD MINING**, promovido por la **Empresa GREENFIELD RESOURCES INC**.

III. OBJETIVO

Hacer efectiva la participación ciudadana en el proceso de evaluación ambiental del Estudio de Impacto Ambiental Categoría III, del proyecto denominado **GREENFIELD MINING** y cumplir con los siguientes aspectos:

- Realizar un Foro Público sobre la base una exposición detallada de la acción propuesta del Estudio de Impacto Ambiental correspondiente.
- Verificar la forma de convocatoria de los participantes, así como los mecanismos de difusión empleados.
- Garantizar una expedita participación de la comunidad directamente afectada o beneficiada.
- Brindar a la comunidad directamente afectada o beneficiada los espacios adecuados para la presentación de sus comentarios sobre el proyecto, obra o actividad y sobre el Estudio de Impacto Ambiental

IV. ALCANCE DEL FORO PUBLICO:

El alcance del Foro Público se realizó en marco a la normativa ambiental vigente (Decreto Ejecutivo 123 del 14 de agosto 2009 y sus modificaciones), que señala la instancia de participación ciudadana, que realiza el Promotor durante la fase de evaluación y análisis del Estudio de Impacto Ambiental, categoría III, en fecha, hora y lugares acordado por el

Promotor y el Ministerio de Ambiente, a la que pueden asistir todas las personas que quieran conocer o realizar observaciones sobre dicho estudio.

V. BREVE DESCRIPCION DEL PROYECTO

El proyecto “Greenfield Mining”, se ha preparado y estructurado contemplando trabajos geológicos, de exploración, producción y beneficio metalúrgicos, con una proyección de explotación de 200 tpd (Ton/día) de producción sostenida de mineral con contenido aurífero, que se explotará mediante labores subterráneas con método de corte y relleno ascendente por subniveles, métodos “trackless” (utilización de equipos mecanizados de bajo perfil que se movilizan sobre llantas y están especialmente diseñados para su uso en minería subterránea) y métodos convencionales, beneficiada metalúrgicamente por cianuración en “pads” y en tanques. El proyecto dentro de su proceso incorpora el concepto de “minería sin residuos” o también denominado concepto de roca total (CRT), evitando la generación de relaves y relaveras.

VI. DESARROLLO DEL FORO PÚBLICO:

Es importante detallar que a solicitud del promotor el Foro Público fue programado para el día lunes 28 de marzo del 2022, en la Casa Comunal de la comunidad de La Gorda, corregimiento de Remance, distrito de San Francisco, provincia de Veraguas, a la 2:30 p.m., a continuación, detallamos datos sobre el evento.

- El día lunes 28 de marzo de 2021, a las 2:30 p.m. (de la tarde), se da inicio al Foro Público correspondiente al Estudio de Impacto Ambiental categoría III, del proyecto denominado **GREENFIELD MINING**, en la Casa Comunal de la comunidad de La Gorda, corregimiento de Remance, distrito de San Francisco. Por parte de los Consultores contratados por la Empresa GREENFIELD RESOURCES INC., explican a los participantes las medidas de bioseguridad por COVID-19, emitidas y autorizadas por el MINSA.
- La Dirección Regional de Veraguas del Ministerio de Ambiente, fungiendo como moderador del Foro Público, cita el objetivo, alcance y mecánica que se establecerá para el desarrollo del mismo, establecido para los Estudio de Impacto Ambiental categoría III, como lo indica la normativa ambiental (Decreto Ejecutivo 123 del 14 de agosto 2009 y sus modificaciones).
- Posteriormente el Ingeniero Roderick Gutiérrez, en representación de la empresa la GREENFIELD RESOURCES INC., da la explicación de la metodología constructiva, objetivos y alcance del proyecto. Prosiguió la presentación por parte de los consultores ambientales, en referencia al Estudio de Impacto Ambiental, detallando el ambiente físico, biológicos, socioeconómico y el Plan de Manejo Ambiental del mismo.
- Paralelo a la exposición de cada panelista, se recordó a los participantes del foro, con la finalidad de que pudiesen formular preguntas, sugerencias, consultas e interrogantes a la información suministrada del proyecto al culminar la presentación.
- Terminada la exposición de los panelistas, se procedió a organizar a los participantes para escuchar las preguntas, inquietudes y sugerencias, por lo que se presentaron un aproximado de 38 preguntas y 45 comentarios y observaciones por parte de las personas presentes en el foro.

Entre las preguntas formuladas las más destacadas son las siguientes:

- ❖ Como el Proyecto hará para que no se contaminen las aguas aledañas al mismo, ni el río Santa María. (derrame de cianuro).
 - ❖ Si el desarrollo del proyecto contempla detonaciones
 - ❖ De donde se obtendrá el agua para la ejecución del Proyecto
- Luego el equipo consultor dio respuesta a la audiencia de cada una de las preguntas expuestas, e intentó aclarar algunos comentarios enfocados a la contaminación de las minas existentes como principal punto de preocupación, por parte de los participantes, entre otras.
- En el período de las preguntas y respuesta se le permitió a la audiencia que expusiera algunas peticiones e inconformidades para con el proyecto, siempre y cuando no interfirieran con el programa del evento, ni con el objetivo de que se pudieran realizar libremente de preguntas y respuestas.
- En horas de las 5:40 p.m. (de la tarde) se dio por culminado el Foro Público correspondiente al Estudio de Impacto Ambiental, categoría III, del proyecto denominado **GREENFIELD MINING**, ubicado en el corregimiento de Remance, distrito de San Francisco, provincia de Veraguas.

VII. SINTESIS DEL FORO PÚBLICO:

El Foro Público se realizó sobre la base de una exposición descriptiva del futuro proyecto que enmarcan el Estudio de Impacto Ambiental categoría III, del proyecto denominado **GREENFIELD MINING**. Además se contó con una audiencia de trescientos cincuenta (350) personas aproximadamente, las que atendieron a la convocatoria en el Foro realizado en la Casa Comunal de la comunidad de La Gorda, corregimiento de Remance, distrito de San Francisco, provincia de Veraguas; sin embargo, en el Foro realizado, tanto residentes, como personas de áreas y distritos aledaños, así como también algunas de instituciones públicas que forman parte de las UAS, involucradas en la atención a la solicitud del Proyecto.

Evidencias Fotográficas de la metodología del Foro Público

CRONOLOGÍA DEL FORO PÚBLICO (casa Comunal de la comunidad de La Gorda)	
	
Figura 1: La Dirección Regional de Veraguas del Ministerio de Ambiente, funge como moderador del Foro Público.	Figura 2: Por parte de la empresa contratista se explica sobre las autorizaciones y medidas de bioseguridad establecidas por el MINSA.
	
Figura 3: Inicio de la presentación del proyecto por parte de los consultores.	Figura 4: Participantes haciendo sus preguntas a los consultores.
	
Figura 5: El público presente, prestando atención a las respuestas por parte de la empresa.	Figura 6: Funcionarios del Ministerio de Ambiente, Regional de Veraguas y Dirección de Evaluación Panamá.
	
Figura 7: Participantes opositores al proyecto de la extracción minera.	Figura 8: Participantes opositores al proyecto de la extracción minera.

VIII. CONCLUSIONES:

Finalmente, el Foro Público del Estudio de Impacto Ambiental categoría III, proyecto denominado **GREENFIELD MINING**, se llevó acabo de manera ordenada y cronológica, donde los presentes expusieron sus interrogantes e inquietudes, el equipo técnico del promotor detalló el motivo de la ejecución del proyecto y respondió cada una de las preguntas elaboradas en el Foro Público.

Hubo participación de Unidades ambientales como el MINSA, SINAPROC, Alcaldía de Santiago y San Francisco, MICI, personal técnico de la Dirección de Evaluación de Panamá

La gran mayoría de los presentes, no están de acuerdo con el desarrollo y ejecución del proyecto, por el temor a la contaminación y afectación que este tipo de proyectos generan.

Preparado por:


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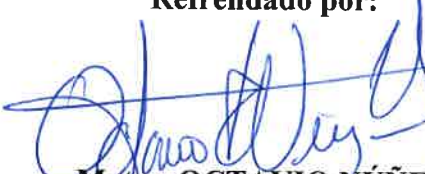

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Refrendado por:


Mgter. OCTAVIO NÚÑEZ
Director Regional de Veraguas – Encargado
Ministerio de Ambiente



REPÚBLICA DE PANAMÁ
MINISTERIO DE AMBIENTE
DIRECCIÓN REGIONAL DE VERAGUAS
Central Telefónica: 500 – 0734 (Ext. 6251)

Santiago, 22 de Abril del 2022
DRVE/ 0359 /2022

Ingeniero
DOMILUIS DOMÍNGUEZ
Director de Evaluación de Impacto Ambiental
Ministerio de Ambiente
En su despacho

Respetado Ingeniero Domínguez:

Remitimos documentación entregada el día 28 de Marzo del corriente por parte del Centro de Incidencia Ambiental (CIAM) y el Concejo Municipal del Distrito de Santiago, durante la realización del Foro Público correspondiente al Estudio de Impacto Ambiental Categoría III titulado “**GREENFIELD MINING**” promovido Greenfield Resources Inc., actividad desarrollada en la comunidad de Piedras Gordas, Corregimiento de Remance, Distrito de San Francisco, Provincia de Veraguas.

Se adjunta: Documentación en Original.

Atentamente,


ING. OCTAVIO NUNEZ
Director Regional Encargado

Dirección Regional MiAMBIENTE/Veraguas.



/ON/YPalacios/

c.c. Archivo
c.c. Expediente





CONCEJO MUNICIPAL DEL DISTRITO DE SANTIAGO
PROVINCIA DE VERAGUAS
RESOLUCIÓN MUNICIPAL N° 3
 (Del 22 de febrero del 2022)



"POR MEDIO DEL CUAL SE RESUELVE RECHAZAR LA CONTAMINACIÓN DEL RÍO SANTA MARÍA Y SE MANIFIESTA OPOSICIÓN A PROYECTO MINERO EN LA CUENCA DEL RÍO SANTA MARÍA"

EL HONORABLE CONSEJO MUNICIPAL DEL DISTRITO DE SANTIAGO EN USO DE SUS FACULTADES LEGALES Y;

CONSIDERANDO:

- Que el Artículo 232 de la Constitución de la República de Panamá, estipula que el Municipio es la organización política autónoma de la comunidad establecida en el Distrito, la cual es democrática y responderá al carácter esencialmente administrativo del gobierno local.
- Que el Artículo 233 de la Constitución de la República señala que: al Municipio, como entidad fundamental de la división político-administrativa del Estado, con gobierno propio, democrático y autónomo, le corresponde prestar los servicios públicos y construir las obras públicas que determine la Ley, ordenar el desarrollo de su territorio, **promover la participación ciudadana, así como el mejoramiento social y cultural de sus habitantes** y cumplir las demás funciones que le asigne la Constitución y la Ley.
- Que los residentes del Distrito de Santiago se ven beneficiados por el Río Santa María el cual nace en el distrito de Santa Fé, provincia de Veraguas, con una superficie de 3,059 Km, desembocando en el Golfo de Parita, vertiente del Pacífico, recorriendo aproximadamente 148 Km de longitud. Y que abastece de agua potable a más de 90 mil personas, dado que en su cuenca se ubica la toma de agua de la potabilizadora del IDAAN, según datos de la propia institución.
- Que sin embargo, el Ministerio de Comercio e Industrias (MICI) a través de la Resolución N° 10 del 12 de enero de 2021, dejó sin efecto la Resolución N° 79 del 26 de junio de 2018, con la cual se decidió cancelar por vencimiento la concesión de exploración otorgada a la empresa Greenfield Resources, Inc. mediante el contrato N° 12 del 27 de junio de 2012.
- Que en la práctica la Resolución N 10 de 12 de enero de 2021, publicada en Gaceta N° 29220 del 17 de febrero de 2021, el Ministerio de Comercio e Industrias, decide dar continuidad al trámite de solicitud de concesión hecha por la empresa Greenfield Resources, Inc. para la extracción de minerales metálicos (oro y otros) en una zona de 2,400 hectáreas ubicada en los corregimientos de Remanse, San Juan y San José, distrito de San Francisco, provincia de Veraguas. Es decir, se ha revivido la antigua mina Remanse que operó en la década de 1990, y que causó posible contaminación, con posibles carencias de planes de contingencia y donde no hizo reparaciones cuando cerraron la mina, hace más de 20 años.
- Que, en vista a que el proyecto minero se encuentra aguas arriba de nuestras tomas de agua cruda y plantas potabilizadoras cualquier fallo en el sistema que afecte nuestra fuente principal de agua, río Santa María, afectaría alrededor de 90 mil personas que se ven beneficiadas de este servicio, teniendo en cuenta que el área de la concesión minera se encuentra cerca a la cuenca del río Santa María, precisamente aguas arriba de dos tomas de agua cruda del Idaan.

Enviado a Patricia J.

- Que los artículos 118 y 119 de la Constitución Política de Panamá establecen el deber fundamental del Estado garantizar que la población viva en un ambiente sano y libre de contaminación, en donde el aire, el agua y los alimentos satisfagan los requerimientos del desarrollo adecuado de la vida humana, además del deber de propiciar un desarrollo social y económico que prevenga la contaminación del ambiente, mantenga el equilibrio ecológico y evite la destrucción de los ecosistemas.
- Que la ley 106 de de 8 de octubre de 1973 en su artículo 17, establece como competencias del Concejo Municipal: Ejercer los acciones constitucionales y legales a que haya lugar, en nombre del Municipio y en defensa de sus derechos; y Dictar medidas a fin de proteger a las personas y las cosas; por lo cual se hace preciso un pronunciamiento en contra de la Resolución N 10 de 12 de enero de 2021.
- Que es una prioridad de este Concejo, proteger a nuestros ciudadanos y garantizarles un ambiente y una calidad de aguas sana, , por lo cual, en virtud de todo lo anterior, y en vista de la gravedad de la situación planteada, EL PLENO DEL CONCEJO EN USO DE SUS FACULTADES LEGALES,

RESUELVE:

PRIMERO: RECHAZAR la Resolución N° 10 de 12 de enero de 2021 emitida por el Ministerio de Comercio e Industrias, a través de la cual se revive el proyecto Minero de Remance, ubicado aguas arriba del Río Santa María por representar un peligro para la calidad del agua potable de los residentes del Municipio de Santiago.

SEGUNDO: RECHAZAR cualquier proyecto minero que ponga en riesgo el medio ambiente, la salud y la calidad de vida de los residentes del Municipio de Santiago.

TERCERO: Esta resolución rige a partir de su aprobación y sanción.

FUNDAMENTO DE DERECHO: LEY 106 DEL 8 DE OCTUBRE DE 1973, REFORMADA POR LA LEY 52 DEL 12 DE DICIEMBRE DE 1984.

DADO Y APROBADO EN LA CIUDAD DE SANTIAGO A LOS VEINTIDOS (22) DIAS DEL MES DE FEBRERO DEL 2022.


H.R. RAUL BATISTA
PRESIDENTE DEL CONCEJO




LICDA. ALMEIDA AGRAZAL
SECRETARIA DEL CONCEJO



Article

Ecological and Health Risk Assessments of an Abandoned Gold Mine (Remance, Panama): Complex Scenarios Need a Combination of Indices

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Abstract: The derelict Remance gold mine is a possible source of pollution with potentially toxic elements (PTEs). In the study area, diverse mine waste has been left behind and exposed to weather conditions, and poses risks for soil, plants and water bodies, and also for the health of local inhabitants. This study sought to perform an ecological and health risk assessment of derelict gold mining areas with incomplete remediation, including: (i) characterizing the geochemical distribution of PTEs; (ii) assessing ecological risk by estimating the pollution load index (PLI) and potential ecological risk index (RI); (iii) assessing soil health by dehydrogenase activity; and iv) establishing non-carcinogenic (HI) and carcinogenic risks (CR) for local inhabitants. Soil health seems to depend on not only PTE concentrations, but also on organic matter (OM). Both indexes (PLI and RI) ranged from high to extreme near mining and waste accumulation sites. As indicated by both the HI and CR results, the mining area poses a health risk for local inhabitants and particularly for children. For this reason, it will be necessary to set up environmental management programs in the areas that are most affected (tailings and surrounding areas) and accordingly establish the best remediation strategies to minimize risks for the local population.

Keywords: potentially toxic elements (PTEs); pollution load index (PLI); potential ecological risk index (RI); dehydrogenase activity (DHA); human risks; Panama

1. Introduction

Mining activities can potentially pollute the environment, especially when tailing materials are left exposed to weather conditions, which favor the release and dispersion of pollutants to the surrounding soil, plants, water bodies and humans [1–4]. The dispersion of potentially toxic elements (PTEs) can be primarily assessed by edaphological characterization and geochemical quantification of pollutants. However, assessing the possible impact on biota requires that certain indices be determined, such as the pollution load index (PLI) to evaluate the degree of contamination; the potential ecological risk index (RI) to evaluate the ecological risk that mine materials can pose [5]. Soil health is the capacity of the soil to function as a vital living ecosystem to sustain plants, animals, and humans [6]. Indicators of soil health provide information about how the soil is functioning with respect to a particular management goal or ecological role [7]. A specific soil function may involve several processes, and each process may be associated with a combination of soil chemical, physical, and biological properties [7]. In this sense, dehydrogenase activity (DHA) is a biological indicator that, added to the rest of the physical and chemical properties measured in this study, allows us to evaluate the health of the soil. Dehydrogenase activity (DHA), as an indicator of “soil health” [8], acts as a monitor of microbiological redox systems and is considered an adequate measure of microbial oxidative activities in soil [9]. DHA also plays a significant role in the biological oxidation of organic matter (OM) by transferring hydrogen from organic substrates to inorganic acceptors [10] and is affected by several factors such as soil moisture, oxidation reduction potential (ORP), reactivity (pH), OM, soil profile depth and concentrations of PTEs [4,9,11]. Thus, it is important to measure these factors and to analyze their relation to DHA.

PTEs in mining areas can be of natural origin because they are components of rocks and ore minerals, whether the area has been exploited or not [12]. Mining activity can promote the distribution of these PTEs (Cu, Zn, As, Sb, Ba, Hg) on the surface and increase their concentrations as a result of mineral weathering, which would increase their potential toxicity [13]. It is necessary to recognize that some PTEs released through mining activity (e.g., Cu, Zn) are also essential elements for life, but are toxic in excess, while even low concentrations of other non-essential (e.g., Hg, Pb) elements are toxic for the environment [14,15]. Some of the pollutants found at high concentrations in the Remance area (As, Hg, Zn, Cu, Ba, Sb and cyanide) are on the priority list of the Agency for Toxic Substances and Disease Registry because these substances can potentially affect human health depending on their toxicity, frequency and exposure at polluted sites [16]. All of these pollutants can cause various health problems: arsenic (As) can cause skin, liver and lung cancers; mercury (Hg) produces neurological damage; zinc (Zn) can weaken the immune system; copper (Cu) can cause abnormalities to the nervous system; barium (Ba) can favor muscle paralysis; antimony can harm the respiratory system [17]; and cyanide can cause headaches and enlarge the thyroid gland, even at low concentrations [18]. Other possible effects of PTEs include carcinogenic and non-carcinogenic ones [1,19].

The objective of this study was to characterize the geochemical distribution of these pollutants in soil and fluvial sediment (including active channel stream sediments and terrace sediments). An ecological and health risk assessment was performed by estimating the PLI and RI indices. Besides DHA, an edaphological characterization was used to provide soil health information. The ultimate objective was to gain complete insights to assess the local risks for human health in this area.

2. Materials and Methods

2.1. Study Area

The Remance gold mine is located in the province of Veraguas in central Panama. The weather in this area is AMI type according to the Köppen-Geiger classification: a humid tropical climate, with the influence of monsoons and annual rainfall >2250 mm, concentrated (60%) in the four wettest months (August–November). Dry months (January–March) have rainfall rates below 60 mm, and the average temperature of the coolest month is

>18 °C [20,21]. The topography in the area is quite irregular, with an altitudinal range between 150 and 266 m.a.s.l. that corresponds to the Veneno stream mouth and the maximum height of hills Principal and Tullido, respectively. The stream is called the Veneno (Poison) because the waters from the first tailings facility used by the Minera Remance company are discharged into it along with the water that flows from the pithead. Plant cover corresponds mostly to bushes, with areas delimited for small-scale agriculture, with rotary burning for crop cultivation and cattle farming [22].

The exploited mineralization corresponds to epithermal gold hosted in pyroclastic rocks, which include several veins distributed in an area covering approximately 10 km² [23] (Figure 1). Mining exploitation has occurred there intermittently since 1800, but we were unable to find details on its extraction processes. The Veraguas Mining Company produced 15,500 tons with 10.5 g of gold extracted per ton from the Remance mine during the 1800s; the Panama Corporation produced another 70,000 tons with 12 g of gold extracted per ton between the years 1923 and 1932 [23]. The last company to operate the site using the cyanidation process [22] was Minera Remance S.A., between 1989 and 1999 [23]; for this period, it reported cumulative production of 53,480 ounces of gold [24]. During this period, many complaints were filed regarding pollution of local water bodies and the Santa María River [22,24]. Presently (June 2021), there is a plan to reinstate mining activity, which has led to local discord [25].

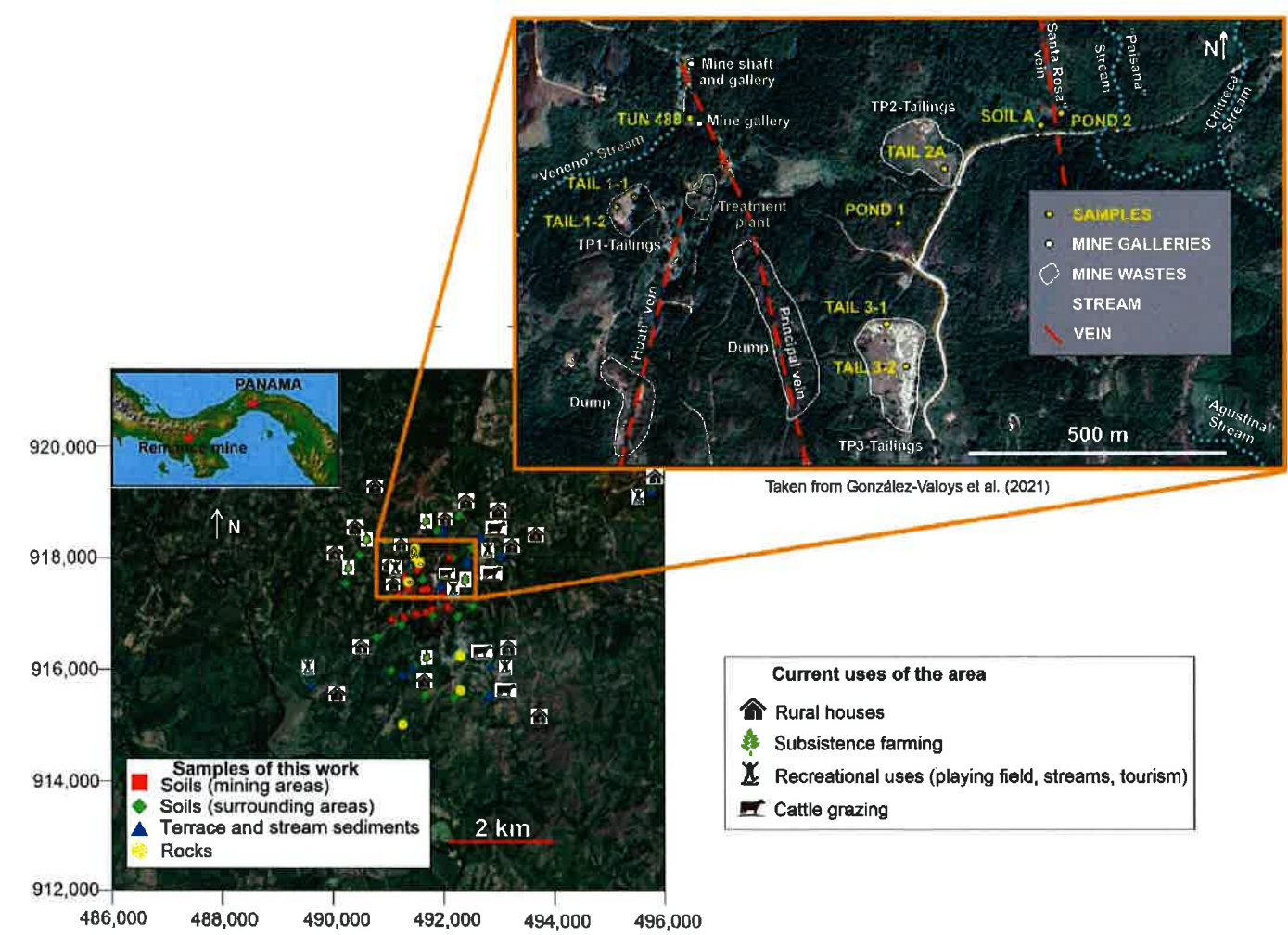


Figure 1. Location map of the samples taken at the Remance gold mine site and use of the area.

A drainage network runs through the area, and includes the Veneno stream, the Chitrecal stream and the La Máquina stream on the slopes of Hill Tullido, excavated to

exploit a quartz stockwork [23]. Possible sources of pollution in the area include mine excavations, which correspond mostly to surface trenches following mineralized veins. Au occurs as small inclusions within pyrite and marcasite, as well as free gold, disseminated within quartz, together with other accessory minerals in small quantities such as chalcopyrite, sphalerite, galena and arsenopyrite. Ag and As are found with Au, along with anomalous amounts of Sb and locally Hg [23]. Other polluting sources are represented by a mine gallery with its continuous water flow, a number of scattered dumps as a result of excavating trenches that evidently contain some proportions of exploited ore minerals and three tailing dams used to concentrate gold ore by means of cyanidation and containing high concentrations of PTEs (Cu, Zn, As, Sb, Ba, Hg, T-CN) according to studies carried out by González-Valoys et al. (2021) [26]. They are all currently exposed to local tropical climate conditions, such as rain (more than 2200 mm/year) and high temperatures, which favor chemical changes in ore and gangue minerals [4], and wind, which favors the aerial dispersion of pollutants [27]. The area is inhabited by peasants, who engage in subsistence activities such as agriculture and livestock farming [22,28]. Hence, the Remance area can be considered a rural, agricultural and recreational site (Tailing 2 is used as a soccer field by inhabitants, and people visit the area to see the old mine; in rural areas, streams are often used for recreational purposes and for water intake for livestock).

2.2. Sampling

Samples were collected between May–June 2019 (wet season) and January 2020 (dry season), and included the following the types:

- 43 soil samples, including 19 samples collected in the mining area around the tailings and excavations of the mine's veins and tunnels, and 24 samples collected within the perimeter of the mine and its surroundings;
- 39 sediment samples, including 19 fluvial active channel stream sediments and 20 fluvial terrace sediment samples taken from the banks of water bodies;
- 7 rock samples collected from outcrops to acquire data about the general lithology in the area.

In order to make a comparison to the regional base level, a background sample for each material type (soil, terrace sediment and stream sediment) was taken approximately 4 km from the mining area, near the town of El Naranjal. Figure 1 shows the locations of samples, mine structures and waste accumulation areas [26]. Table S1 displays the sample codes and typology, along with geographic coordinates.

Soil samples were taken using a PVC tube at a depth of 0–30 cm from the potentially most affected zone. Sediment samples were collected with plastic shovels from the top 5–10 cm. All of the samples weighed about 3 kg each and were stored in plastic bags at room temperature prior to sample preparation.

2.3. Sample Preparation and Analysis

All of the samples were dried at room temperature in the laboratory, disaggregated and passed through a 2 mm sieve. Afterward, some representative aliquots were extracted according to different analytical determinations. The subsamples taken to determine DHA were transported in hermetically sealed bags and were cold-stored. An aliquot of the samples taken at <2 mm (50 g) was crushed in an agate mortar to a <100 µm grain size to determine the concentrations of PTEs (Cu, Zn, As, Sb, Ba, Hg) and for mineralogy identification purposes. Another aliquot was used to determine certain edaphic parameters: pH, electrical conductivity (EC), ORP. The methodology to perform these analyses included a 1:5 suspension (*w/v*) (ASTM D 4972) [29], and determination was performed using a multi-parameter benchtop Orion Versa Star Pro device. Other established edaphological parameters included OM, quantified by weight loss at 455 °C (ASTM D 2974) [29], and cationic exchange capacity (CEC), established by the potentiometer method [30]. Color when wet was measured by Munsell soil charts. The soil texture classification was determined by the Bouyoucos method described by Porta [31].

The concentrations of Cu, Zn, As, Sb and Ba were analyzed by energy dispersive X-ray fluorescence spectroscopy (ED-XRF) with Epsilon1 equipment (Panalytical brand) [4]. Total Hg (THg) was determined by Zeeman atomic absorption spectroscopy with high-frequency modulation of light polarization (ZAAS-HFM) using commercial equipment Lumex RA-915 M with a pyrolytic attachment (PYRO-915+) [32]. Certified reference material was employed to check both precision and accuracy: NIST 2710A (Montana soil), with recovery percentages between 95–105%. The analysis of total cyanide, cyanide complexes and easily leachable cyanide was performed by the ALS Global laboratory using the cyanide (CN) complexes according to Standard UNE-EN ISO 14403-2 [33].

DHA was determined by the triphenyltetrazolium chloride (TTC) method [34–36] on samples selected after considering variabilities in As and Cu to assess the influence of the concentrations of these PTEs on this enzymatic activity. Dehydrogenase converts 2,3,5-TTC into triphenyl formazan (TPF) [36]. The homogenized soil samples (1.5 g) were placed inside test tubes (15 × 120 mm) and were mixed with 1.5 mL of deionized water, 0.015 g of CaCO₃ and 0.250 mL of TTC (3% *v/w*) to be vortexed (2 min) and incubated (Memmert In 30) at 37 °C for 24 h. Next, samples were vortexed (4 min) with methanol used as the extractor agent (5 mL). Tubes were centrifuged (Ortoalresa, Unicen 21) at 4000 rpm for 10 min, and the supernatant was obtained and analyzed in a UV visible spectrophotometer (Biochrom, Libra S60) at 485 nm. The results were expressed as µg TPF d^{−1} g^{−1}.

Mineralogy was analyzed by X-ray powder diffraction (XRD) using a PAN analytical X-Pert PRO X-ray diffractometer fitted with a Cu anode. The operating conditions were 40 mA, 45 kV, 0.5° divergence slit and 0.5 mm reception slits. Samples were scanned with a step size of 0.0167° (2θ) and 150 ms per step. Characterization of samples was performed by the powder method between 5 and 55° (2θ). The Match v.3 and Fullprof software for the Rietveld analysis were used for the quantification [37–39]. The Crystallography Open Database (COD) reference patterns were utilized to identify mineral phases.

2.4. Methods

2.4.1. Pollution Index and Pollution Load Index

Soil quality can be estimated by various indices [40]. A site polluted by a certain element can be assessed by the pollution index (PI) (Equation (1)), and the same, but with more than one element, can be determined by the pollution load index (PLI) [5,41] using Equation (2).

$$PI = C_{soil} / C_{background} \tag{1}$$

$$PLI = (PI_1 \times PI_2 \times \dots \times PI_n)^{1/n} \tag{2}$$

where C_{soil} and C_{background} are the concentrations of the particular PTE in the soil and background samples, respectively (mg kg^{−1}). The PLI is the pollution load index of several elements, and the PI is the single pollution index for a certain element. Table 1 presents the evaluation criteria for the PLI [5].

Table 1. Evaluation criteria for the pollution index (PI), the pollution load index (PLI), the toxicity response coefficient (Er) and the potential ecological risk index (RI).

Index	No Polluted	Slightly Polluted	Moderately Polluted	Considerably Polluted	Seriously Polluted	Extremely Polluted
PLI/PI	<1	1 < PLI < 2	2 < PLI < 3	PLI > 3	-	-
Er	<10	<40	40 < Er < 80	80 < Er < 160	160 < Er < 320	Er > 320
RI	<50	<150	150 < RI < 300	300 < RI < 600	600 < RI < 1200	RI > 1200

2.4.2. Toxicity Response Coefficient and the Potential Ecological Risk Index

Hakanson [42] defined RI as an index that combines environmental effects and element toxicity with the aim of considering the general ecological migration and transformation trends of these elements in soils and sediments. Pan et al. (2019) [5] defined the toxic-

ity response coefficient (Er) as the single potential ecological risk for a certain element (Equation (3)), which is used to obtain RI (Equation (4)):

$$Er^i = PI \times Tr^i \tag{3}$$

$$RI = Er_1 + Er_2 + \dots + Er_n \tag{4}$$

where Er^i is the single RI , PI is the single pollution index for a certain element and Tr^i is the toxicity response coefficient of element i . The Er calculation is based on Hakanson’s element toxicity response coefficient standards [42], which can be given as follows: $Hg = 40$, $As = 10$, $Cu = 5$, $Zn = 1$ and $Sb = 7$ [43]. Table 1 summarizes the evaluation thresholds for these indices based on the respective proposers.

2.4.3. Human Health Risk Assessment

Some PTEs released from mining waste and incorporated into different environmental compartments can have an immediate effect on human health. The assessment was performed by using the average daily doses (ADD) through three pathways: accidental soil ingestion (ADD soil ingestion); skin contact (ADD dermal contact) [19,44–46]; and soil dust inhalation (ADD inhalation) [1,47]. Additionally, both the HI and CR risks were assessed in different scenarios: residential, agricultural and recreational [19,48].

ADDs were calculated as $mg\ kg^{-1}\ day^{-1}$ as follows (Equations (5)–(7)):

$$ADD\ soil\ ingestion = (C_{soil} \times CF \times IR_{ing} \times FI \times EF \times ED \times RBA) / (BW \times AT) \tag{5}$$

$$ADD\ dermal\ contact = (C_{soil} \times CF \times AF \times ABS_d \times EF \times ED \times EV \times SA) / (BW \times AT) \tag{6}$$

$$ADD\ inhalation = (C_{soil} \times IR_{air} \times EF \times ED) / (BW \times AT \times PEF) \tag{7}$$

where C_{soil} is the concentration of PTEs in soil in $mg\ kg^{-1}$; CF is the conversion factor ($1 \times 10^{-6}\ kg\ mg^{-1}$); BW is body weight (70 kg in an adult, 15 kg in a child); IR_{ing} is the ingestion rate in soil; FI is fraction ingested; EF is exposure frequency; ED is exposure duration; RBA is the relative bioavailability factor (unitless); AT is the averaging time; AF is the adherence factor; ABS_d is the dermal absorption factor (unitless); EV is event frequency; SA is the skin surface area; IR_{air} is the inhalation rate; and PEF is the soil-to-air particulate emission factor ($m^3\ kg^{-1}$). All of these parameters are presented in Table 2 for the three exposure pathways in three scenarios. The constants for the PTEs used in the study appear in Table 3.

Table 2. The exposure parameters used for the study calculations.

Parameter	Unit	Residential		Recreational		Agricultural Adult
		Adult	Child	Adult	Child	
Exposure frequency (EF)	day year ^{−1}	365	365	96	96	250
Exposure duration (ED)	year	30 ^a	6	30 ^a	6	40
Averaging time (AT)						
Non carcinogenic	year day	ED × EF	ED × EF	ED × EF	ED × EF	ED × EF
Carcinogenic		70 × EF	70 × EF	70 × EF	70 × EF	70 × EF
Ingestion						
Ingestion rate in soil (IR _{ing})	mg kg ^{−1}	100	200	100	200	100
Fraction ingested (FI)	unitless	1	1	1	1	1
Dermal contact						
Adherence factor (AF)	mg (cm ² event) ^{−1}	0.07	0.2	0.07	0.2	0.07
Event frequency (EV)	events day ^{−1}	1	1	1	1	1
Skin surface area contact (SA)	cm ²	6032	2373	6032	2373	6032 ^b
Inhalation						
Inhalation rate (IR _{air}) ^a	m ³ day ^{−1}	20	10	20	10	20
Particulate emission factor (PEF)	m ³ kg ^{−1}	1.36 × 10 ⁹	1.36 × 10 ⁹	1.36 × 10 ⁹	1.36 × 10 ⁹	1.36 × 10 ⁹

^a Values taken from Department of Environmental Affairs [47]. ^b Value equaling exposure of an adult who engages in agricultural work in the same rural environment. The other values were taken from Gruszecka-Kosowska et al. (2020) [19].

Non-Carcinogenic Risk

The HI risk was calculated with the hazard quotient (HQ) as follows (Equation (8)):

$$HQ = ADD/RfD \tag{8}$$

where ADD is the average daily dose for soil ingestion, dermal contact or inhalation as $mg\ kg^{-1}\ day^{-1}$, and RfD is the reference dose for oral, dermal or inhalation as $mg\ kg^{-1}\ day^{-1}$. Table 3 presents the RfD values for the three exposure pathways: RfDo (oral reference doses), RfDd (dermal reference doses) and RfDinh (inhalation reference doses). RfDd was calculated according to Wcislo et al. (2016) [49] and Gruszecka-Kosowska et al. (2020) [19].

The total HI risk of PTEs was determined by the hazard index (HI_t) [48], as Equation (9) shows:

$$HI_t = HQ1 + HQ2 + \dots + HQ_n \tag{9}$$

where HQs are the hazard quotient values for the 1–n PTEs herein investigated.

Table 3. The toxicological parameters used for the calculations in this study. Abbreviations: RBA, relative bioavailability factor; ABS_d, dermal absorption factor; GIABS, fraction of contaminant absorbed in the gastrointestinal tract; RfDo, oral reference doses; RfDd, dermal reference doses; RfDinh, inhalation reference doses; Sfo, slope factor for oral; SF_d, slope factor for dermal; SF_{inh}, slope factor for inhalation. RBA, ABS and GIABS are unitless, Reference doses (RfD) in $mg\ kg^{-1}\ day^{-1}$ and slope factors (SF) in $(mg\ kg^{-1}\ day^{-1})^{-1}$.

Element	(Unitless)			RfD ($mg\ kg^{-1}\ day^{-1}$)			SF ($mg\ kg^{-1}\ day^{-1}$) ^{−1}		
	RBA ^a	ABS _d ^a	GIABS ^b	RfDo ^b	RfDd ^c	RfDinh ^d	Sfo ^e	SF _d ^c	SF _{inh} ^d
Cu	1	0.01	1	4.0×10^{-2}	4.0×10^{-2}	–	1.7	1.7	–
Zn	1	0.01	1	3.0×10^{-1}	3.0×10^{-1}	–	–	–	–
As	0.6	0.03	1	3.0×10^{-4}	3.0×10^{-4}	3.0×10^{-4}	1.5	1.5	15
Sb	1	0.01	0.15	4.0×10^{-4}	2.7×10^{-3}	–	–	–	–
Ba	1	0.01	0.07	2.0×10^{-1}	2.9×10^0	–	–	–	–
Hg	1	0.01	0.07	3.0×10^{-4}	4.3×10^{-3}	8.6×10^{-5}	–	–	–

^a Values taken from Gruszecka-Kosowska et al. (2020) [17]. ^b Values taken from USEPA [50]. ^c Values calculated according to Wcislo et al. (2016) [49] and Gruszecka-Kosowska et al. (2020) [19]. ^d Values taken from Kamunda et al. (2016) [1]. ^e Values taken from Pan et al. (2019) [5].

Carcinogenic Risk

CR risks were calculated as follows (Equation (10)):

$$CR = ADD \times SF \tag{10}$$

where ADD is the average daily dose for soil ingestion, dermal contact or inhalation as $mg\ kg^{-1}\ day^{-1}$ and SF is the slope factor for oral, dermal or inhalation over a lifetime for a particular PTE that plays a key role in daily toxin intake and results in an increased risk of an individual developing cancer [1,5]. Table 3 presents the SF values for the three exposure pathways. SF_d was calculated according to Wcislo et al. (2016) [49] and Gruszecka-Kosowska et al. (2020) [19].

The total CR risks of PTEs were determined according to the CR_t values [48] as follows (Equation (11)):

$$CR_t = CR1 + CR2 + \dots + CR_n \tag{11}$$

where CR_t are the CR risk values for the 1–n PTEs investigated in this study.

The total risk for both the HI and CR risks was calculated by the sum of the risks for the different exposure pathways: (Equation (12)):

$$Risk\ (total) = Risk\ (ingestion) + Risk\ (dermal) + Risk\ (inhalation) \tag{12}$$

2.4.4. Statistical Analyses

Microsoft Excel spreadsheets were used to manage the results. Minitab 15 was employed to analyze the statistical parameters of the analytical results. A multivariate analysis was performed by applying Ward’s linkage to obtain significant dendrograms. A factor analysis and a principal component analysis (PCA) were applied to search for the influence of factors, or group of factors, using “Varimax” orthogonal rotation.

The distribution maps of PTEs, PLI, RI, HI and CR were generated with the Surfer 9 software, licensed by the UCLM, using the option “inverse distance to a power (2)” to generate the corresponding distribution maps.

3. Results

3.1. Total Contents

The average concentrations of the PTEs from the different material types in the sampled Remance gold mine areas are presented in Table 4, while all of the obtained results appear in Table S2. pH ranged between 3.9 and 5.9. The most acidic value was found in pithead sediments and the most neutral one in the mining work areas. EC ranged between 0.03 to 0.52 dS m^{−1}, with the lowest value in the mining area and the highest value in pithead sediments. OM varied between 0.8% and 12.9%, with the smallest amount in tailings and the largest amount in pithead sediments.

Table 4. Average values and standard deviation of the physicochemical parameters and PTEs (mg kg^{−1}) in the different material types in the sampled areas.

Sample Type	N	pH	EC	OM (%)	Cu	Zn	As	Sb	Ba	Hg
			(dS m ^{−1})							
Soils (mining area) ^a	19	5.9 ± 0.5	0.03 ± 0.03	8.2 ± 3.8	61.3 ± 51.8	46.9 ± 23.9	56.4 ± 54.4	13.7 ± 2.6	200.6 ± 123.5	0.11 ± 0.16
Soils (surrounding areas) ^a	24	5.2 ± 0.4	0.05 ± 0.04	5.1 ± 2.0	93.5 ± 85.6	62.8 ± 35.9	35.5 ± 44.2	16.4 ± 5.4	349.7 ± 198.0	0.06 ± 0.06
Terrace sediments ^a	20	5.3 ± 1.0	0.14 ± 0.22	4.3 ± 2.2	65.2 ± 32.7	55.3 ± 18.8	152.7 ± 210.3	19.8 ± 8.9	355.7 ± 115.0	0.62 ± 1.48
Stream sediments ^a	19	5.8 ± 0.5	0.07 ± 0.08	3.4 ± 2.7	74.5 ± 40.0	66.3 ± 34.1	143.4 ± 131.7	23.2 ± 12.5	398.7 ± 125.5	0.21 ± 0.25
Tailings ^b	5	4.1 ± 0.8	0.29 ± 0.57	0.8 ± 0.2	77.7 ± 107.4	27.0 ± 15.2	614.1 ± 222.7	17.8 ± 5.6	376.2 ± 164.6	1.37 ± 1.12
Cyanidation ponds ^b	4	4.9 ± 0.2	0.09 ± 0.02	5.3 ± 1.7	10.9 ± 7.0	37.1 ± 22.9	41.0 ± 19.7	1.4 ± 0.7	253.9 ± 64.8	0.17 ± 0.07
Pithead sediments ^b	1	3.9	0.52	12.9	403.0	153.0	5030.0	2.2	55.4	0.62

^a This work. ^b Values according to González-Valoys et al. (2021) [26].

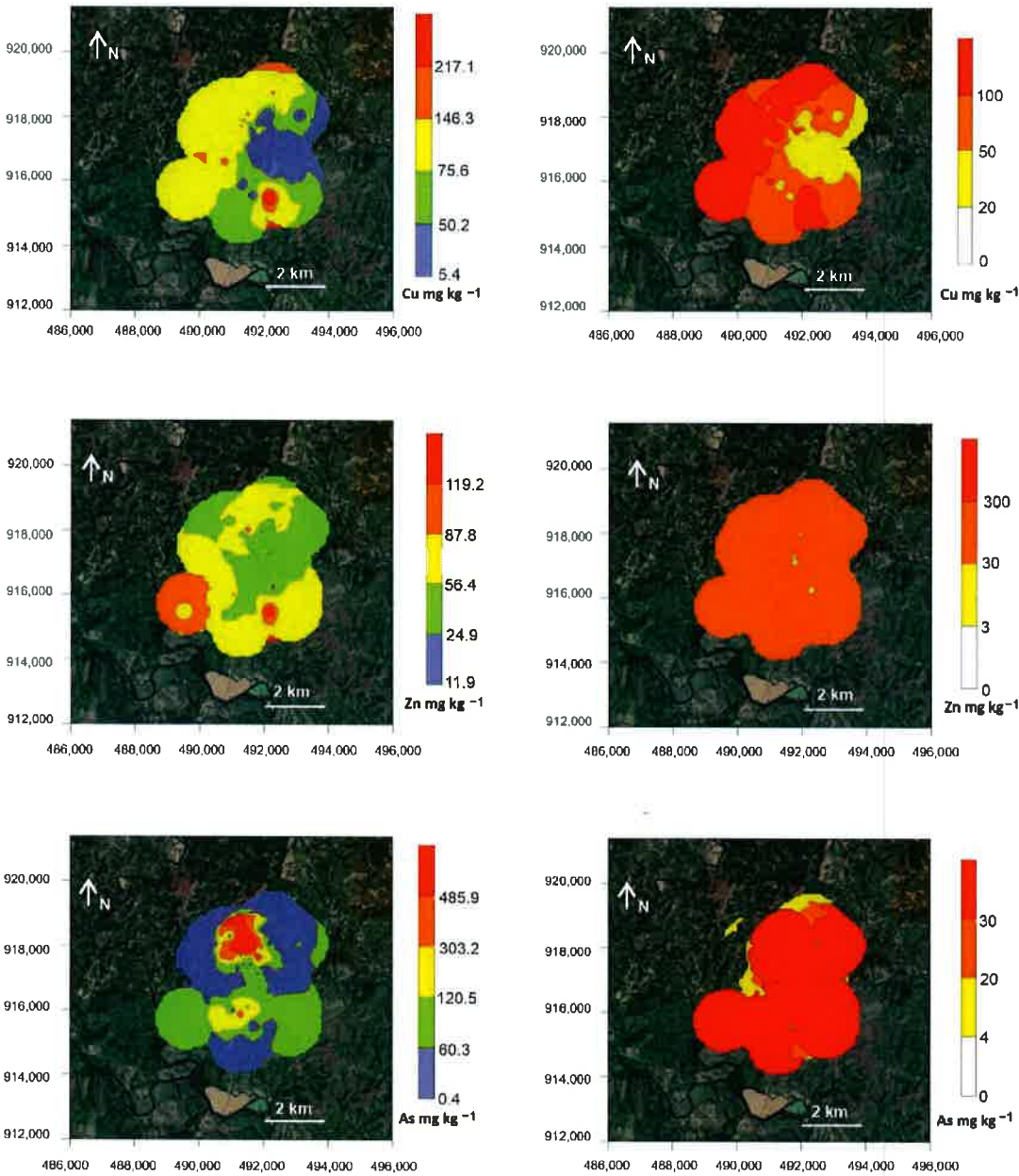
The concentrations of Cu varied between 10.9 and 403.0 mg kg^{−1}, and those of As from 41.0 to 5030.0 mg kg^{−1}, with the lowest concentration in cyanidation ponds and the highest in pithead sediments. Cyanidation ponds are the final part of the process, and then join the streams [22]; these have been exposed to rain currents for more than 20 years. Pithead sediments are sediments that come out of the galleries of the mine, located in the “principal” vein, where underground water flows; this water current is then incorporated into a “Veneno” stream. Zn concentrations varied between 27.0 and 153.0 mg kg^{−1}, with the lowest in mine tailings and the highest in pithead sediments. Sb concentrations ranged from 1.4 to 23.2 mg kg^{−1}, and those of Ba between 55.4 and 398.7 mg kg^{−1}, with the lowest in cyanidation ponds and the highest in stream sediments for both elements. Hg concentrations ranged from 0.06 to 1.37 mg kg^{−1}, with the lowest in soils from the surrounding areas and the highest in mine tailings. The last tailings were from mining operations in 1999. Mercury is one of the elements present in mineralization in small amounts [23], which is why it can be present in tailings after mining.

The order of the average concentration of PTEs was: Ba > As > Cu > Zn > Sb > Hg in stream sediments and terrace sediments, Ba > Cu > As > Zn > Sb > Hg in the soils from the mining area and Ba > Cu > Zn > As > Sb > Hg in the soils from the surrounding area.

The average PTE concentrations for rocks from outcrops, as determined by ED-XRF (ST2), were: Cu (40.3 mg kg^{−1}), Zn (22.8 mg kg^{−1}), As (122.7 mg kg^{−1}), Sb (25.7 mg kg^{−1}), Ba (239.7 mg kg^{−1}) and T(Hg) (0.17 mg kg^{−1}).

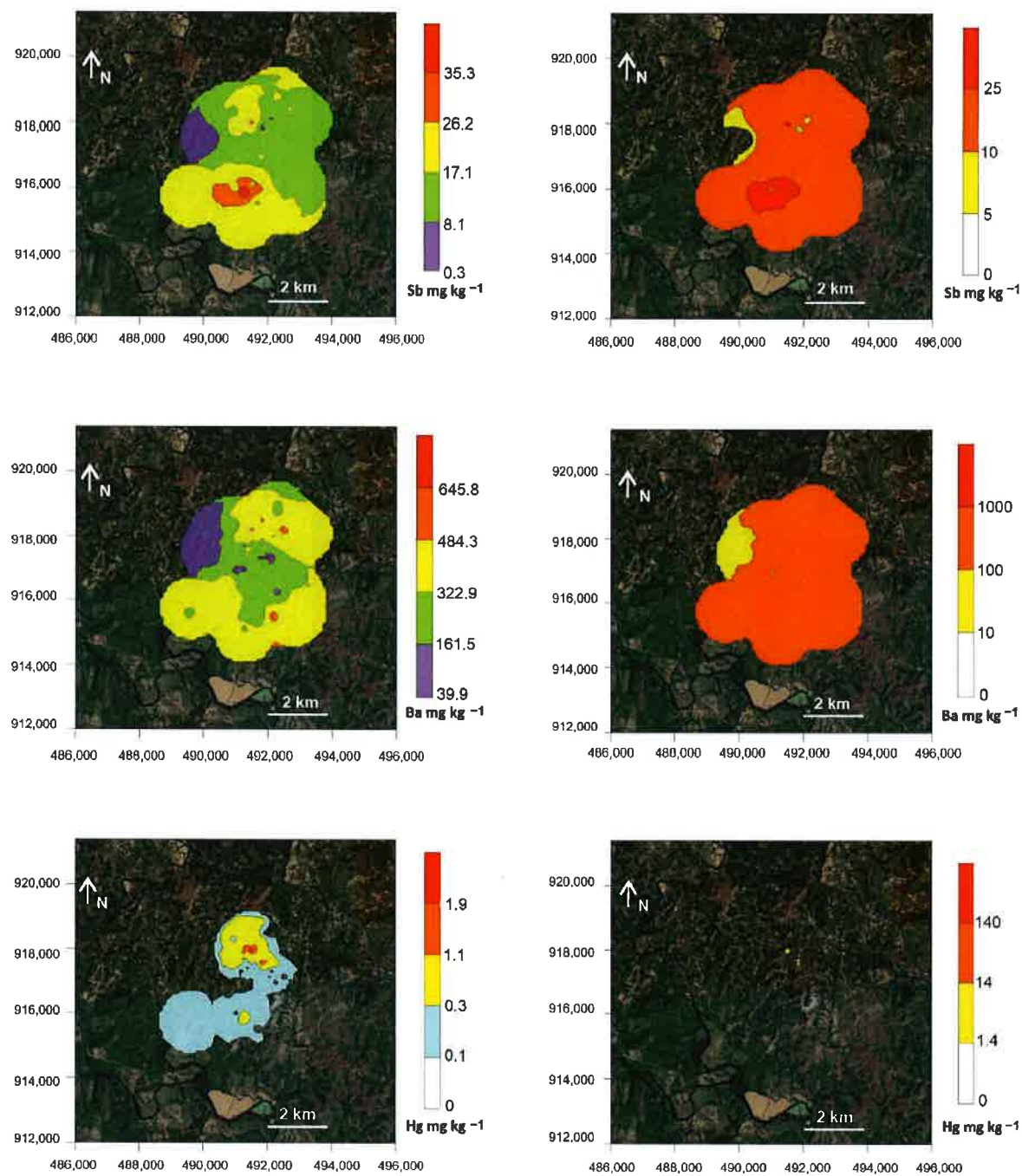
3.2. Spatial Variability

Isoconcentration maps were generated to analyze the geographical distribution of the analytical results. One set of maps indicates the concentration thresholds (minimum value, average -1σ , average, average $+1\sigma$, average $+2\sigma$), while another set displays the results according to the guideline values indicated in Table 5 for agricultural, residential and industrial uses (Zn, As, Ba and Hg according to the Panama Standard; Cu and Sb according to the Costa Rica Standard). The PTE concentrations were high over almost the entire perimeter of the study area, and surpassed the Cu and As guideline values, even for industrial-use levels, while Zn, Sb and Ba exceeded the values set out in the standard for residential use. The exception was Hg, which exceeded the value for agricultural use only in tailings (Figure 2A,B).



(A)

Figure 2. Cont.



(B)

Figure 2. (A) Distribution maps for Cu, Zn, and As. Left: according to the statistical figures; right: according to the soil guideline values listed in Table 5 (yellow: agricultural limit; orange: residential limit; red: industrial limit). Distribution maps of PTEs generated using the concentration values for soils (surrounding areas), soils (mining areas), stream sediments, terrace sediments, tailings, cyanidation ponds and pithead sediments. (B) Distribution maps for Sb, Ba and Hg. Left: according to the statistical figures; right: according to the soil guideline values listed in Table 5 (yellow: agricultural limit; orange: residential limit; red: industrial limit). Distribution maps of PTEs generated using the concentration values for soils (surrounding areas), soils (mining areas), stream sediments, terrace sediments, tailings, cyanidation ponds and pithead sediments.

Table 5. Soil guidelines for the PTEs for Panama and Costa Rica (all values are expressed as mg kg^{−1}).

Soil Guidelines	Uses	Cu	Zn	As	Sb	Ba	Hg	Reference
Panama Maximum permissible limits of soil contaminants for human health	Others		3	4		10	1.4	[51]
	Residential		30	20		100	14	
	Industrial		300	30		1000	140	
Costa Rica	Prevention Value	20	300	5	2	150	0.5	[52]
Intervention value	Agricultural	20	450	35	5	300	12	
(Concentration above which there are potential direct or indirect risks to human health)	Residential	50	1000	55	10	500	36	
	Industrial	100	2000	150	25	750	70	

3.3. Mineralogical Analysis

Table 6 presents the estimated percent abundance of the identified minerals for the selected samples from soils, terrace sediments and stream sediments. The diffractograms of studied samples are compiled in Figure S1. The main mineral phases identified in soils were quartz (89%), kaolinite (10%) and illite (1%), while terrace sediments were composed of quartz (84%), kaolinite (11%), feldspar (3%), illite (1%) and chlorite (1%). Stream sediments comprised quartz (84%), kaolinite (11%), and chlorite (5%). The found mineral phases were similar in soils and sediments (terrace sediments and stream sediments) and the main phases were quartz and kaolinite. The presence of PTEs could be associated with clay fractions, such as kaolinite and illite [53], due to no characteristic minerals of these PTEs being detected in the XRD analysis. Consequently, the most plausible explanation is the absorption/adsorption of the PTEs by clays, as they were the minerals with the highest representation.

Table 6. The estimated percent abundance of the mineral phases identified for the selected samples.

Sample	Sample Type	Kaolinite (%)	Illite (%)	Chlorite (%)	Quartz (%)	Feldspar (%)
TR EU 3	Terrace sediments	traces	n.d.	n.d.	100	n.d.
TR J1	Terrace sediments	10	n.d.	traces	85	5
TR J2	Terrace sediments	5	n.d.	n.d.	90	5
TR J3	Terrace sediments	15	5	n.d.	75	5
TR R2	Terrace sediments	15	n.d.	n.d.	85	n.d.
TR R9	Terrace sediments	15	n.d.	n.d.	85	n.d.
TRB	Terrace sediments	15	n.d.	5	80	n.d.
TERR 17	Terrace sediments	10	n.d.	5	75	10
SDEU2	Stream sediments	10	n.d.	25	65	n.d.
SDJ2	Stream sediments	10	n.d.	n.d.	90	n.d.
SDJ3	Stream sediments	10	n.d.	5	85	n.d.
SDR2	Stream sediments	15	n.d.	n.d.	85	n.d.
SDR9	Stream sediments	15	n.d.	n.d.	85	n.d.
SED17	Stream sediments	5	n.d.	traces	95	n.d.
SA6S	Soils (surrounding areas)	10	n.d.	n.d.	90	n.d.
SR5S	Soils (surrounding areas)	10	n.d.	n.d.	90	n.d.
SR6S	Soils (surrounding areas)	10	n.d.	n.d.	90	n.d.
S2LS	Soils (surrounding areas)	10	5	n.d.	85	n.d.

n.d.: not detected; traces: signal appears but is below the detection limit (<100 ppm).

3.4. DHA and Correlations with Edaphic Parameters and PTEs

The DHA values were higher in soils than in terrace sediments and were lower in stream sediments ($63.27 > 37.47 > 24.79 \mu\text{g TPF g}^{-1} \text{ d}^{-1}$), contrary to what was reported in soils and sediments in Morro do Ouro, the largest industrial gold mine in Brazil [54]. The DHA values of the present work were lower than those measured in other contaminated soils in the Ventanas Cu smelter, situated in the Puchuncaví Valley of Central Chile ($110 \text{ mg TPF g}^{-1} \text{ d}^{-1}$) [55], in Almadenejos located in the mining district of Almadén, Spain ($484 \text{ mg TPF g}^{-1} \text{ d}^{-1}$) [36], and in restored soils from mine sites ($140\text{--}580 \text{ mg TPF g}^{-1} \text{ d}^{-1}$) reported by Mukhopadhyay and Maiti (2010) [56]. To seek correlations between pollution of the area and its biological activity, a statistical analysis was performed. Table 7 presents the average values of the DHA results, the physicochemical parameters, and the concentrations of PTEs, total cyanide (T-CN), complex cyanide (C-CN) and easily releasable cyanide (E-CN) for soils, terrace sediments and stream sediments. The same trend was found in the OM ($5.3 > 4.2 > 3.4\%$) and CEC ($10.61 > 9.74 > 9.08 \text{ cmol kg}^{-1}$) data, while As showed higher concentrations in stream sediments and terrace sediments and lower concentrations in soils ($188.9 > 146.5 > 55.7 \text{ mg kg}^{-1}$). Some elements (Cu and Zn) presented higher concentrations in soils than in sediments, while total cyanide presented a more complex fractionation.

Table 7. Summary of the average values and standard deviation of edaphic parameters, DHA (in $\mu\text{g TPF g}^{-1} \text{ d}^{-1}$) and concentrations of PTEs and cyanide expressed in mg kg^{-1} . Abbreviations: EC, electrical conductivity; ORP, oxidation reduction potential; OM, organic matter; CEC, cationic exchange capacity; T-CN, total cyanide; C-CN, complex cyanide; and E-CN, easily released cyanide.

Sample Type	pH	EC dS m ^{−1}	ORP mV	OM %	CEC cmol kg ^{−1}	Cu	Zn	As	Sb	Ba	Hg	DHA	T-CN	C-CN	E-CN
Terrace sediments	5.3 ± 1.0	0.14 ± 0.22	489.2 ± 132.6	4.2 ± 2.2	9.7 ± 2.4	66.0 ± 32.0	56.5 ± 19.1	146.5 ± 206.6	18.8 ± 9.7	365.2 ± 119.8	0.59 ± 1.44	37.47 ± 43.31	<1.0	<1.0	<1.0
Stream sediments	5.7 ± 0.6	0.07 ± 0.05	441.3 ± 117.3	3.4 ± 2.4	9.1 ± 2.0	74.0 ± 59.0	77.7 ± 44.3	188.9 ± 145.3	25.5 ± 13.0	429.5 ± 137.8	0.30 ± 0.31	24.79 ± 34.13	1.3 ± 1.5	1.2 ± 1.1	<1.0
Soils (surrounding areas)	5.3 ± 0.4	0.07 ± 0.05	507.0 ± 86.0	5.3 ± 2.2	10.6 ± 4.5	111.7 ± 127.4	80.4 ± 45.6	55.7 ± 50.7	19.0 ± 6.0	430.8 ± 127.1	0.08 ± 0.08	63.27 ± 43.39	1.0 ± 0.8	<1.0	<1.0

3.5. Multi-Elemental Analysis

According to the mineralogical analysis, the samples were very similar (soils, terraces sediments and stream sediments), which is why we grouped them all together to perform the dendrogram and PCA. In the dendrogram obtained from the cluster analysis (Figure 3), Cu appears to be associated with Zn in one group, while As, Hg, Sb and Ba appear in another group. To determine the strength of the relationships between DHA and edaphic parameters, multivariate principal component analysis (PCA) was used (Figure 4, Table 8). Although the relationships were not so strong, the most significant in the first main component (PC1) and positively related to DHA (0.384) were T-CN (0.464), OM (0.379), C-CN (0.369), E-CN (0.333) and CEC (0.202), and negatively related to ORP (−0.334) and Ba (−0.160); while in the second principal component (PC2), As (−0.489), Sb (−0.424) and Hg (−0.423) were negatively related.

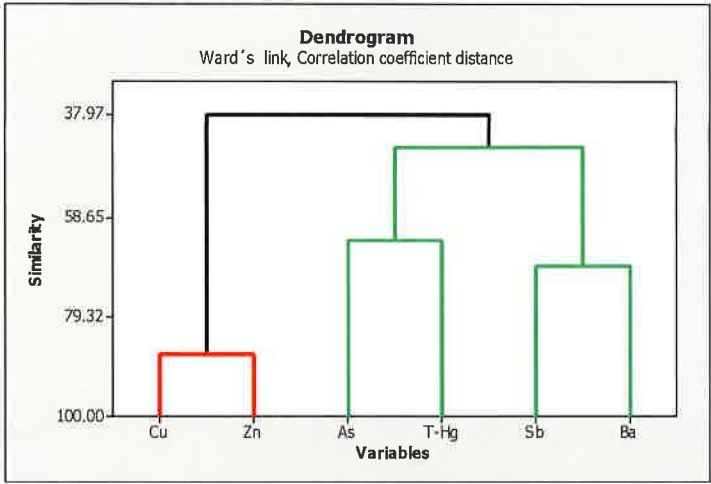


Figure 3. Dendrogram of the relations between the concentrations of PTEs in the study. Dendrogram generated with the data from soils, terrace sediments and stream sediments.

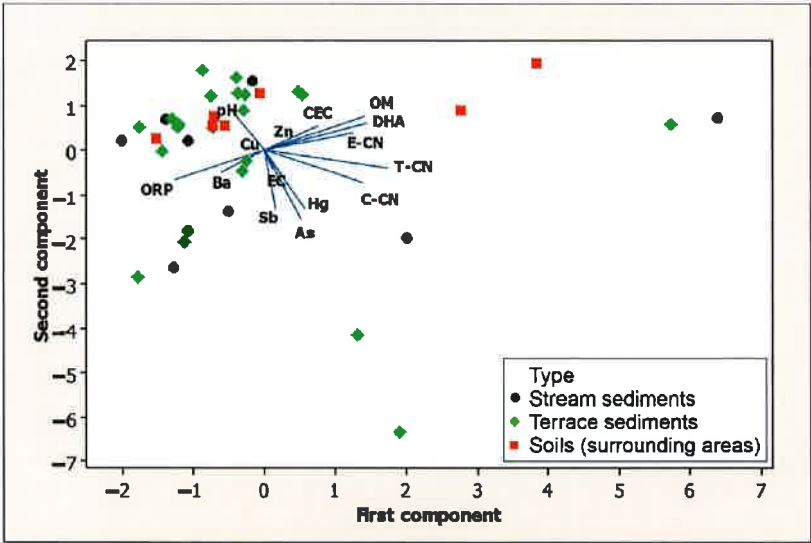


Figure 4. DHA and relationship with edaphic parameters, PTEs and cyanide. Generated with the data from soils, terrace sediments and stream sediments.

Table 8. Principal component analysis matrix for the relationship between DHA and edaphic parameters. Numbers in bold correspond to PC1 or PC2 more significative.

Variable	PC1	PC2
pH	−0.131	0.319
EC	0.034	−0.141
ORP	−0.334	−0.204
OM	0.379	0.247
CEC	0.202	0.177
Cu	−0.018	−0.019
Zn	0.074	0.048
As	0.141	−0.489
Sb	0.044	−0.424
Ba	−0.160	−0.161
Hg	0.154	−0.423
DHA	0.384	0.190
T-CN	0.464	−0.125
C-CN	0.369	−0.227
E-CN	0.333	0.122

3.6. Pollution Index (PI) and Pollution Load Index (PLI)

Table 9 presents the PI and PLI values, and Figure 5 provides the PLI map. According to the evaluation criteria for PI and PLI presented in Table 1, the PI indicated serious pollution ($PI > 3$) in the different studied areas. Within these, the tailings and the pithead that showed the highest PI values due to the materials of both areas were the main sources of PTEs in the nearby environment.

Table 9. The PI and PLI average values and standard deviation calculated for the different sample types in the Remance mine area.

Type	PI Cu	PI Zn	PI As	PI Sb	PI Ba	PI Hg	PLI
Soils (mining area) ^a	1.3 ± 1.1	0.6 ± 0.3	1.4 ± 1.4	0.9 ± 0.2	0.4 ± 0.2	1.6 ± 2.4	0.7 ± 0.3
Soils (surrounding areas) ^a	1.9 ± 1.8	0.8 ± 0.5	0.9 ± 1.1	1.1 ± 0.4	0.7 ± 0.4	1.0 ± 0.9	0.7 ± 0.4
Terrace sediments ^a	0.8 ± 0.4	0.7 ± 0.2	5.4 ± 7.4	6.6 ± 3.0	0.7 ± 0.2	15.9 ± 37.9	1.9 ± 1.2
Stream sediments ^a	1.1 ± 0.6	0.9 ± 0.5	5.8 ± 5.3	1.3 ± 0.7	0.8 ± 0.2	6.1 ± 7.5	1.6 ± 0.8
Tailings ^b	11.1 ± 15.3	1.0 ± 0.5	33.0 ± 12.0	59.3 ± 18.7	1.6 ± 0.7	9.1 ± 7.5	7.3 ± 3.0
Cyanidation ponds ^b	1.6 ± 1.0	1.3 ± 0.8	2.2 ± 1.1	4.7 ± 2.4	1.1 ± 0.3	1.1 ± 0.5	1.6 ± 0.3
Pithead sediments ^b	57.6	5.5	270.4	7.3	0.2	4.1	9.2

^a This work. ^b Values calculated with the data obtained from González-Valoys et al., 2021 [26].

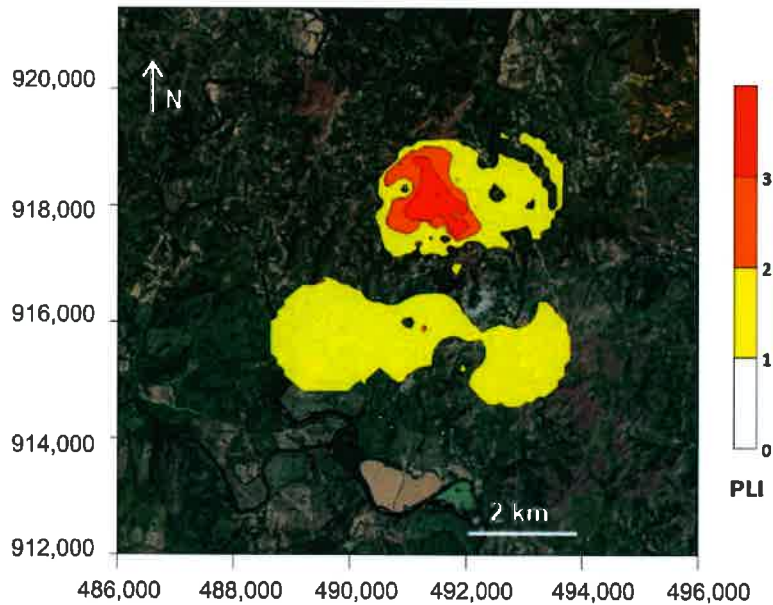


Figure 5. Distribution map of PLI for Cu, Zn, As, Sb, Ba and Hg. Distribution maps of PLI generated using the concentration values for soils (surrounding areas), soils (mining areas), stream sediments, terrace sediments, tailings, cyanidation ponds and pithead sediments.

The PLI followed this order: pithead sediments > tailings > terrace sediments > stream sediments = cyanidation ponds > soils from the mining area and soils (from the mining and surrounding areas). The PLI map shows an area with moderate to considerable damage corresponding to and around the tailings and pithead area, followed by slight damage to the surrounding area and south of the mining concession.

3.7. Toxicity Response Coefficient (Er) and Potential Ecological Risk Index (RI)

The values calculated for Er and RI of Cu, Zn, As, Sb and Hg are shown in Table 10, while Figure 6 presents the geographical distribution for RI. According to the evaluation criteria presented in Table 1 for Er and the toxicity according to each element, the Er values suggests that tailings have a damaging role in the area, as well as the pithead; thus the terrace sediments and stream sediments have been significantly impacted and represent

important sources of risk due to their content of As, Hg and Sb; in the case of soils from the mining area, Hg is the only major concern.

Table 10. Average values and standard deviation of Er and RI for the different sample types.

Type	Er Cu	Er Zn	Er As	Er Sb	Er Hg	RI
Soils (surrounding area)	9.5 ± 8.8	0.8 ± 0.5	8.9 ± 10.8	7.8 ± 2.5	38.1 ± 35.4	65 ± 44
Soils (mining area)	6.4 ± 5.4	0.6 ± 0.3	14.1 ± 13.6	6.5 ± 1.2	65.5 ± 97.4	93 ± 108
Terrace sediments	4.1 ± 2.0	0.7 ± 0.2	51.6 ± 72.7	44.2 ± 22.1	605.6 ± 1481.2	706 ± 1554
Stream sediments	5.5 ± 2.9	0.9 ± 0.5	55.3 ± 52.8	9.0 ± 4.8	233.1 ± 295.0	304 ± 337
Tailings ^a	55.5 ± 76.7	1.0 ± 0.5	330.2 ± 119.7	415.1 ± 131.1	365.9 ± 299.0	1168 ± 509
Cyanidation ponds ^a	7.8 ± 5.0	1.3 ± 0.8	22.0 ± 10.6	32.7 ± 16.9	44.7 ± 19.6	109 ± 32
Pithead sediments ^a	287.9	5.5	2704.3	51.3	165.3	3214

^a Values calculated with the data obtained from González-Valoys et al., 2021 [26].

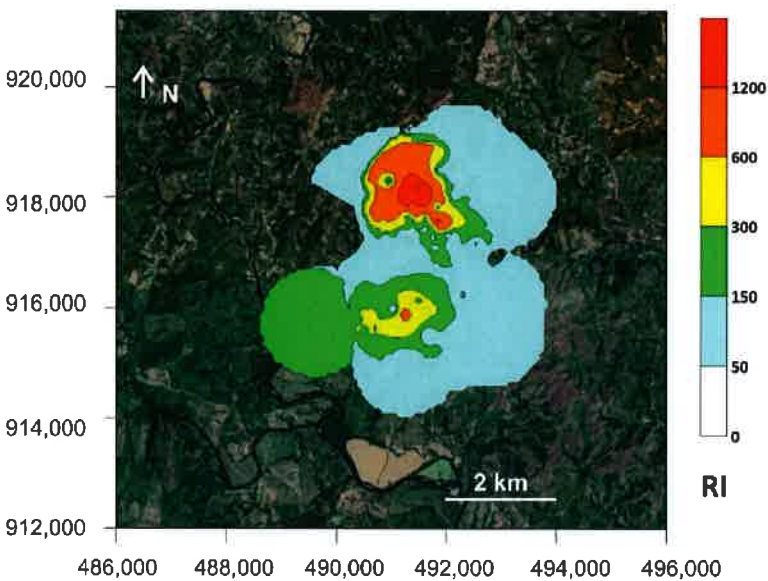


Figure 6. Geographical distribution of RI for Cu, Zn, As, Sb and Hg. Distribution maps of RI generated using the concentration values for soils (surrounding areas), soils (mining areas), stream sediments, terrace sediments, tailings, cyanidation ponds and pithead sediments.

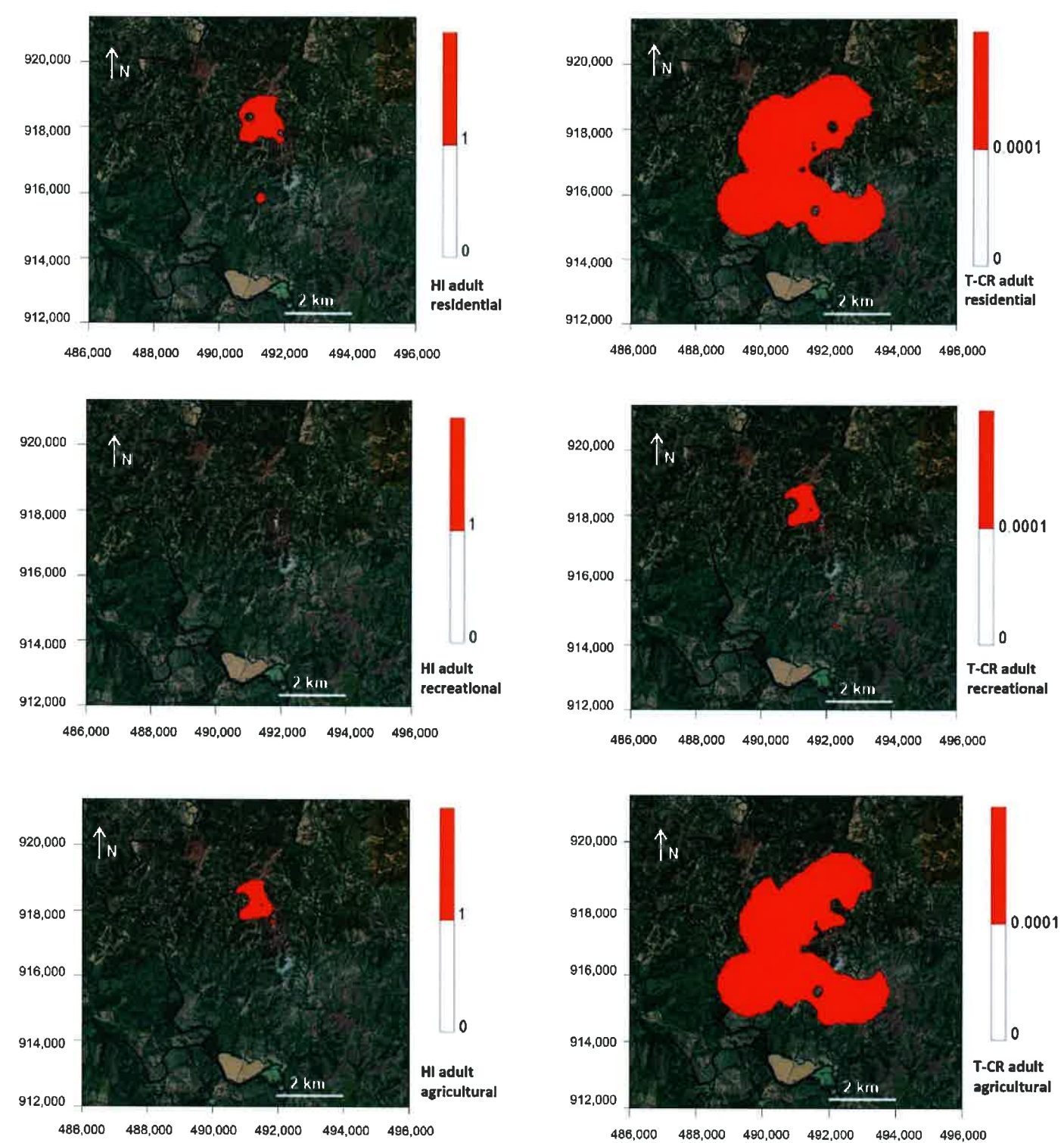
The average RI values and their distribution indicate a gradation in risk as follows: pithead sediments (extreme risk); tailings and terrace sediments (serious risk); stream sediments (high risk); cyanidation ponds, soils from the mining area and soils from the surrounding areas (mild risk). One remarkable finding indicated that the areas at higher risk coincided with those with higher PLI values for As, Sb, Ba and Hg (Figure 5), with an extensive area representing a serious to extreme RI that also corresponded to the area near tailings and pithead sediments.

3.8. Human Health Risk Assessment

3.8.1. Non-carcinogenic Risk (HI)

The limit for HI and HQ risks is 1; those that exceed this value are considered high risk [48]. The average estimated total HI (soil ingestion, dermal contact and inhalation) risks assumed for children and adults in the different scenarios (residential, recreational, agricultural) are presented in Supplementary Table S3. Figure 7B represents the distribution of the HI risks for children in the residential and recreational scenarios. In the residential scenario for children, the value was exceeded in all areas and in this order: pithead sediments > tailings > terrace sediments > stream sediments > soils from the mining area > soils from the surrounding areas> cyanidation ponds

(150.31 > 19.03 > 5.29 > 5.12 > 2.18 > 1.67 > 1.30, respectively). In the recreational scenario, the HI limit was exceeded in the following areas: pithead sediments > tailings > terrace sediments > stream sediments (39.53 > 5.00 > 1.39 > 1.35, respectively) (Table S3).



(A)
Figure 7. Cont.

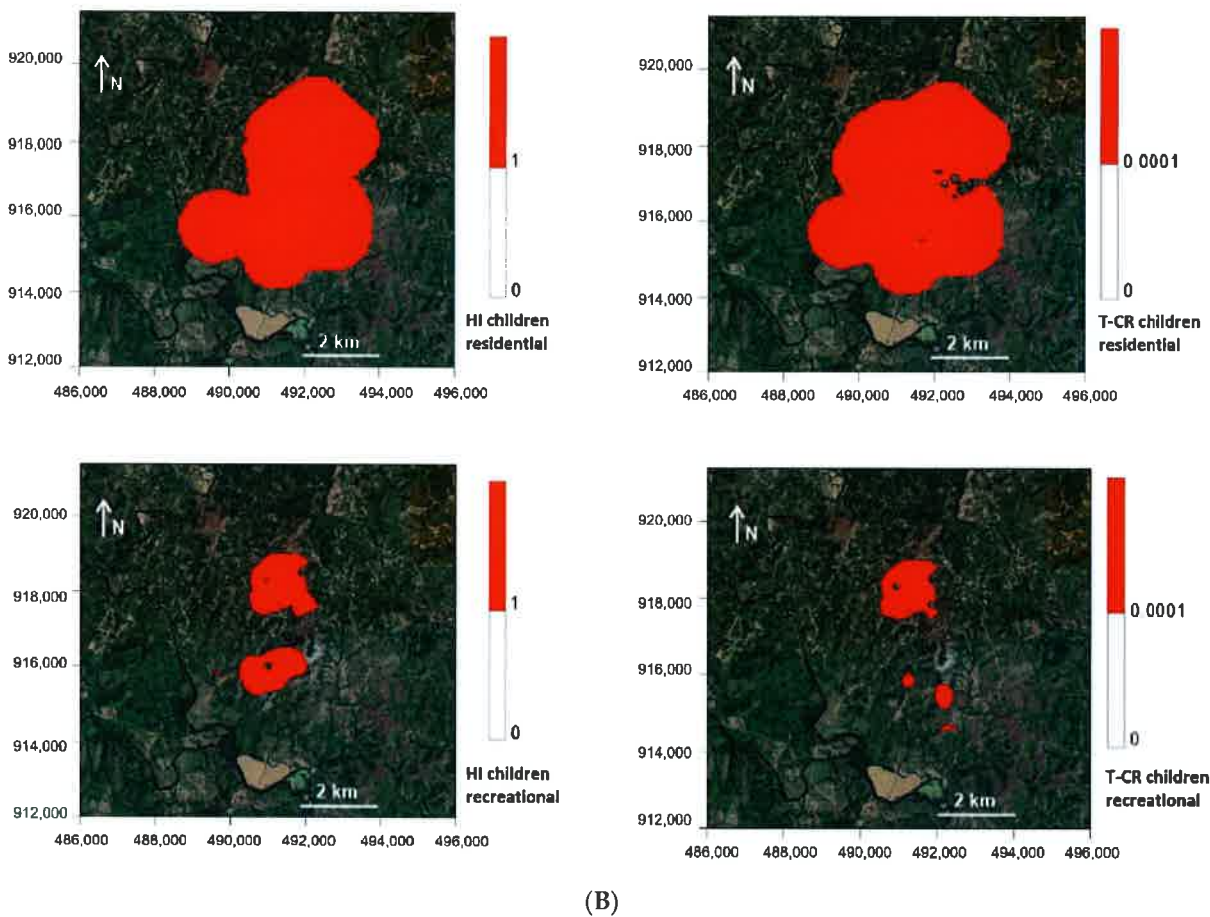


Figure 7. (A) Non-carcinogenic risk and carcinogenic risk maps for adults in the residential, recreational and agricultural scenarios. Risk calculated by the concentration values for soils from surrounding areas, soils from mining areas, stream sediments, terrace sediments, tailings, cyanidation ponds and pithead sediments. (B) Non-carcinogenic risk and carcinogenic risk maps for children in the residential and recreational scenarios. Risk calculated by the concentration values for soils from surrounding areas, soils from mining areas, stream sediments, terrace sediments, tailings, cyanidation ponds and pithead sediments.

The HI map for adults in the residential, agricultural and recreational scenarios is shown in Figure 7A, and the average values are summarized in Supplementary Table S3. The HI risks for adults were surpassed in pithead sediments in both the residential and agricultural scenarios (17.44 and 11.94, respectively), and also in tailings in the same two scenarios (2.20 and 1.51, respectively). This threshold in the recreational scenario was surpassed only in pithead sediments (4.59).

The HI risks were much higher for children than for adults, and the ingestion route contributed the most. In it, As showed the highest values (exceeding HQ). The HQ value through which HI risks were represented by PTEs was evaluated and exceeded by As through the ingestion route for children (residential) and adults (residential and agricultural), and through dermal contact for children in the residential scenario.

3.8.2. Carcinogenic Risk (CR)

The acceptable CR risk level was set to equal 1×10^{-6} for an individual PTE and to equal 1×10^{-4} for the sum of carcinogenic PTEs [19,48]. Values exceeding these are considered CR. The average values of total CR (soil ingestion, dermal contact and inhalation) represented by the materials studied for children and adults in the different scenarios (residential, recreational, agricultural) are presented in Supplementary Table S4. Figure 7B also presents the CR maps for children in the residential and recreational scenarios. For the children in the residential scenario, the following areas were above the acceptable

limit: pithead sediments > tailings > stream sediments = terrace sediments > soils from the surrounding areas > soils from the mining area ($6.6 \times 10^{-3} > 8.6 \times 10^{-4} > 3.1 \times 10^{-4} = 3.1 \times 10^{-4} > 2.3 \times 10^{-4} > 1.9 \times 10^{-4}$, respectively). In the recreational scenario, pithead sediments (1.7×10^{-3}) and tailings (2.3×10^{-4}) were above the acceptable value.

Figure 7A depicts the CR maps for adults in the residential, agricultural and recreational scenarios; values are presented in Supplementary Table S4. The acceptable value for the residential scenario was exceeded in the following areas: pithead sediments > tailings > stream sediments > terrace sediments > soils from the surrounding areas > soils from the mining area ($3.8 \times 10^{-3} > 4.9 \times 10^{-4} > 1.8 \times 10^{-4} > 1.7 \times 10^{-4} > 1.3 \times 10^{-4} > 1.0 \times 10^{-4}$, respectively). That for the agricultural scenario was exceeded in this order: pithead sediments > tailings > stream sediments = terrace sediments > soils from the surrounding areas ($3.5 \times 10^{-3} > 4.5 \times 10^{-4} > 1.6 \times 10^{-4} = 1.6 \times 10^{-4} > 1.1 \times 10^{-4}$, respectively). In the recreational scenario, this value was exceeded in pithead sediments (1.0×10^{-3}) and tailings (1.3×10^{-4}). CR risks were much higher for children than adults, and the highest risk route was soil ingestion, followed by dermal contact. The acceptable value for a single PTE (1×10^{-6}) was exceeded for Cu and As in the residential and agricultural scenarios.

4. Discussion

Observing the dispersion maps of Remance PTEs (Figure 2) with respect to local legislation, the total concentrations of As and Cu are those that represent a potential impact on the area, taking into consideration that a study of mobile concentrations (bioavailability) is required to ensure that these elements are indeed present in concerning concentrations. The PCA showed that DHA was favored by the presence of OM and cyanide species in soils, terraces and stream sediments. Furthermore, As and Hg were positive factors (PC1) if DHA was present, as Campos et al. (2018) [36] described in a mining and metallurgical complex of Hg. In the Remance mine scenario, only the higher Cu concentrations seemed to affect soil health in terms of DHA levels. This is surprising evidence for a gold mine with cyanidation during the metallurgical process, but it evidences the need to merge some risk indices for an appropriate initial risk assessment. It is worth mentioning that a complete risk assessment involves acquiring a big dataset that includes data on the pollutants in all environmental compartments and local food supplies, as well as a complete study of the local population's life habits, such as the origin of the food they eat, the time they spend in local polluted areas, among many more [57–59].

A first risk assessment stage should involve the precise delimitation of affected areas. For this purpose, it is necessary to apply indices capable of comparing the levels of PTEs in polluted areas with background areas. Although some indices properly describe the release of certain elements to the environment, a complex scenario such as the Remance mine requires combining a group of elements with similar dispersion patterns. As shown in Figure 5, the PLI shows the impact mainly of the tailing area, pithead sediments, and its surroundings, showing how the contamination has spread from the tailings and pithead sediments; the other zone with a lower degree of impact is to the south of the mine, where excavation work took place. The information provided by the PLI data seems more meaningful than the application of single enrichment factors or applying similar indices to single elements [60].

A second stage should provide information about the degree of effects to biota. It is necessary to state that establishing the bioavailability and transfer rates of PTEs can be challenging, but some indices can provide an initial view of these effects to biota based on a generic dataset. Tailings and pithead are the source of contamination by PTEs affecting the surrounding soils and downstream sediments, as evidenced by the Er and RI. Distribution maps delimit two small areas with considerable damage, including mining materials and some sediments downstream. With this simple approach, it is possible to better delimit the areas indicated by PLI that probably affect biota. The final stage must evaluate the effects of these restricted areas on the local population's health. As some elements of the Remance mine are carcinogenic, a combination of HI and CR indices is needed to better

delimit risk areas. As expected, risk areas are small dimensions for children's recreational use (both HI and CR), but delimit an area with larger CR dimensions for agricultural use. Obviously, HI and CR for children in residential areas appear with larger values, except HI for adults. The main factors related to the distribution of risk areas were the presence of As, Sb and Hg, which is consistent with many other case studies of mining and industrial pollution in China [61]. Another remarkable finding was that the CR risks for adults and for agricultural uses were wider than expected, as the RI only revealed mild damage for soil samples. Looking at the pollutants that exceeded the accepted levels of risk to human health, the main one was As because it can cause skin, liver and lung cancer, while excess Cu can cause abnormalities of the nervous system [17].

The ecological and health risk assessments of the Remance area revealed that these mining areas are complex scenarios in which many (synergistic and antagonistic) factors must be considered. Although soil health did not seem to be affected by the presence of PTEs, or was even positively affected by them, these PTEs can pose a high risk in some areas, especially areas with recreational uses for children and agricultural uses.

5. Conclusions

The abandoned Remance mine poses a risk for the health of the environment and its inhabitants, as different indicators revealed. In particular, the RI best expressed the environmental risk, which coincided with the results of CR and HI to human health.

The areas with the highest risk were pithead sediments, tailings, terrace sediments and stream sediments, which were the areas that still had a strong impact due to mining activity and, to a lesser degree, impacted the mining work area, cyanidation ponds and soils. These results were corroborated by soil health as assessed through DHA, which showed that soil health was better than that of terrace sediments and stream sediments.

According to Er and PI, the elements that posed a risk for the environment were $As > Hg > Sb > Cu$. The main HI was constituted by As through ingestion and dermal contact, and As and Cu for the CR through ingestion and dermal contact. In all cases, the worst scenario was for children, and for adults in residential, recreational and agricultural scenarios. This is a major concern because peasants live in the study area with their families, and they perform agricultural work and live there on a generally permanent basis.

From a human health point of view, the most relevant pollutant was As because it can cause skin, liver and lung cancer and represented HI and CR through ingestion and dermal contact pathways. More details on the bioavailability of elements are needed in order to realistically assess the risks related to the presence of this element in the area.

Given all of the above considerations for both environmental and human health, it is necessary to set up environmental management programs in these areas to establish the best remediation strategies [62–64] and help preserve the right to health and to live in a clean environment.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/ijerph18179369/s1>. Table S1: Sample codes and typology, along with geographic coordinates, Table S2: Result of samples, Table S3: Non-carcinogenic risk, Table S4: Carcinogenic risk, Figure S1: Diffractograms.

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Environmental challenges related to cyanidation in Central American gold mining; the Remance mine (Panama)

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ABSTRACT

Mine tailings are a potential source of environmental pollution because they typically contain potentially toxic elements (PTEs) and the residue of chemical compounds used during extraction processes. The Remance gold mine (NW Panama) is a decommissioned mine with mining activity records dating from the 1800s and several periods of abandonment. Very little remediation work has been performed, and waste is exposed to climatic conditions. This study aimed to evaluate the PTEs and cyanide contents in mine waste after mining operations ceased some 20 years ago, and to evaluate the degree of pollution and the environmental risks they pose with the use of the Pollution Load Index (PLI) and the Ecological Risk Index (RI). Although the total cyanide (T-CN) concentration (1.4–1.9 mg kg⁻¹) found in most of the study area falls within the limits of gold mining tailing values for American sites (1.5–23 mg kg⁻¹), it is worth noting that the values of the tailings of the last used mining operation exceed it (25.2–518 mg kg⁻¹) and persist at the site. The PLI and RI suggest that the tailings from the mine and mine gallery sediments represent a source of pollution for soils and surrounding areas given their high content of PTEs (As, Cu, Sb, Hg) and T-CN, which pose serious ecological risks for biota. Therefore, it is necessary to draw up a remediation plan for this area.

1. Introduction

Gold mining is perhaps the most widespread and most practiced mining type in the world, performed by large mining companies and small groups of miners. These mining operations work with very low mineral/waste ratios and produce large volumes of waste after concentration processes. These concentration processes often employ compounds with a high toxic environment potential, such as cyanide compounds or Hg, which are also used inefficiently in Indonesia, Colombia, Brazil, Ecuador, Ghana, among other countries

(Velásquez-López et al., 2011; Seccatore et al., 2014; García et al., 2015; Clifford, 2017). Gold mining production depends on mining technology and efficiency, and the highest levels are mined in South America, with intermediate levels in Asia and Central America, and low levels in Africa (Seccatore et al., 2014). The degree of pollution produced by a gold mining operation depends on the nature and composition of the extracted minerals (Kyle et al., 2011, 2012; Luque-Almagro et al., 2016), the extraction process (Higuera et al., 2004; Olobatoke and Mathuthu, 2016) and the taken remediation measures, which are often inadequate or insufficient (O'Faircheallaigh and Corbett, 2016). Gold appears in

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ores with other elements like metals and metalloids, which can be an environmental concern when mining operations spread them in the environment (Drace et al., 2016; Pavoni et al., 2018; García-Lorenzo et al., 2019; Elmayel et al., 2020).

Mine tailings are focal pollution points for surroundings, and often contain high levels of metals and metalloids, e.g., Fe, Cu, Zn, As, Sb, Cd, Hg, Pb (Eisler and Wiemeyer, 2004; Shaw et al., 2006; Donato et al., 2007; Veiga et al., 2014; García-Lorenzo et al., 2019; BasriSakakibara and Sera, 2020). They are generally considered to be potentially toxic elements (PTEs) (Hooda, 2010), and environmental factors like rain, wind and erosion lead to the mobilisation of metals and waste (Meeussen et al., 1992; Hilson and Murck, 2001; García-Giménez and Jiménez-Ballesta, 2017; Ramappa and Muniswamy, 2018). Soil and sediment properties, such as pH, texture, clay minerals, Fe and Al oxy-hydroxides, among others, play a crucial role in the geochemical mobility of toxic metals in areas affected by gold mining (Palansooriya et al., 2020). This problem is combined with the fact that most ore-processing companies use one of the most toxic chemical products, cyanide, to leach out the valuable elements contained in mined ore (Shaw et al., 2006; Donato et al., 2008; Ramappa and Muniswamy, 2018; Anning et al., 2019). These mines require solution-processing ponds that contain alkaline waters, and high concentrations of sodium cyanide, free cyanide and metal-cyanide complexes (Donato et al., 2008). Given their cyanide content, these water bodies are an environmental risk, which is compounded in the event of accidental spillages in rivers and streams because cyanide volatilises at a high rate and releases hydrogen cyanide to air (Brüger et al., 2018). This process potentially affects agricultural areas, plants and groundwater, and also poses a risk for human and animal health (Khan et al., 2020).

The cyanide types typically found in gold mine tailings are free cyanide (HCN , CN^-), which is easily released, weak acid dissociable (WAD) cyanide (Cu, Ni, Zn) (these complexes are unstable and break up, and free cyanide is released into the environment) and stronger cyanide complexes (Au, Co, Fe), which do not release cyanide, but decompose slowly and are stabler than WAD cyanides in sunlight and under strongly acid conditions (Meeussen et al., 1992; Anning et al., 2019). Cyanide at low concentrations in soil can biodegrade in the presence of nitrifying bacteria, but higher concentrations caused by anthropogenic activities, such as manufacturing industries, the application of herbicides and mining operations, impact both soil and the environment (ATSDR, 2006). Cyanide is harmful for human health, even at low concentrations, and over long periods. The workers who breathe in small amounts of hydrogen cyanide, i.e., between 6 and 10 mg m^{-3} , for a lengthy period can have breathing difficulties, chest pains, vomiting, changes in blood, headaches and enlarged thyroid gland. Breathing high concentrations causes death, and skin that comes into contact with hydrogen cyanide and cyanide salts can be irritated with sores (ATSDR, 2006).

In light of all this, the present study aimed to assess the implications of the contents of PTEs and total cyanide that remain in Remance gold mine tailings in Panama more than 20 years after the mining company shut down its operations. The obtained information was used to evaluate the pollution risks for the environment, which were evaluated with the use of the Pollution Load Index (PLI) and the Ecological Risk Index (RI). It was hypothesized that the remaining amounts of these pollutants still pose risks for both human health and the environment. Therefore, this study lays the basis to establish remediation plans in the area.

2. Materials and methods

2.1. Study area

The Remance mine belongs to the gold-rich strip of the Veraguas province in Panama and corresponds to an epithermal gold deposit hosted on a bed of pyroclastic rocks. The hydrothermal alteration covers an area of 10 km^2 , and gold is found in veins as either small inclusions in pyrite and marcasite (FeS_2) or free gold disseminated within quartz,

with small amounts of accessory minerals in the form of chalcopyrite (CuFeS_2), sphalerite (ZnS), galena (PbS) and arsenopyrite (FeAsS) (Nelson and Ganoza, 1999). The geochemical surveys conducted by the company Minera Remance S.A. have revealed high levels of PTEs in the area, including Au, Ag and As, as well as localised Hg and anomalous amounts of Sb (Nelson and Ganoza, 1999). The deposit comprises a system of veins, in which the principal vein contains the biggest ore quantities, along with minor, but important, veins like Santa Rosa and Consuelo, which are subterranean and have sporadic outcrops (Nelson and Ganoza, 1999). The mine was mainly operated on a subterranean basis during intermittent periods between 1800 and 1999 by three different companies (Nelson and Ganoza, 1999), and the relatively rudimentary technology employed in the process, at least by the last company, resulted in low production levels and major environmental problems (Hughes-Ortega, 1998). The features that are still visible in the mine area are two mine galleries and one mine shaft, as well as accumulated waste, which includes mine sterile rock (dumps) and dams that, in turn, include cyanidation process waste. These waste types have been exposed to local environmental effects related to the local tropical climate for at least the last two decades.

According to the Köppen climate classification map (Dirección de Hidrometeorología de ETESA, 2007), the local climate is the Ami type, a humid tropical climate with a monsoon influence, annual rainfall of >2250 mm, a dry season lasting 5 months and a lengthy rainy season. The study area presents a mountainous physiography with average slopes between 35 and 50% in the central elevated area, where the presence of loose materials from mineral processing with insufficient plant cover can increase the risk of these materials' erosion, and cause their transport to lower topographically areas during torrential rain periods.

While the company Minera Remance S.A. ran its operations between 1989 and 1999 (Nelson and Ganoza, 1999), the cyanidation process was used to extract the precious metal. It stated neutralising the sodium cyanide employed during the process with sodium hypochlorite. Over the years, three tailings ponds were utilised to contain the corresponding mine waste:

- Tailings Pond 1 (TP1): used from April 1990 to March 1992. This pond is located NW of the mining concession to one side of the so-called Veneno (poison in Spanish) stream, and stored approximately 75,000 tonnes of tailings, with a front wall measuring 27 m high (Gómez, 2008). The area has a plain relief and is now employed as a football ground
- Tailings Pond 2 (TP2): it is located NE of the mining concession at the head of the *Chitreca* stream and it stored 100,000 m^3 of waste material. This pond was employed from April 1992 to October 1994, when it was ordered to be closed as a result of a wall collapsing following an extreme precipitation event during the rainy season, which led to the *Chitreca* stream being polluted with mine waste material (Gómez, 2008).
- Tailings Pond 3 (TP3): it was built as a replacement following the collapse of TP2. This pond is located in the centre of the mining concession on the eastern hill slope where the '*Principal*' vein is found, and the area has a less pronounced slope than that of TP2. This pond was employed from October 1994 until operation shyt down (Gómez, 2008). Unlike the previous tailing points, TP3 was not positioned directly in a natural basin and, following treatment in sedimentation ponds, the tailings wash water was discharged to the *Agustina* stream, which flows into the mid course of the *Chitreca* stream which, in turn, flows into the River Santa María (Delgado, 1994).
- Secondary Ponds SP1 and SP2: the use of these ponds is unclear in terms of the local mining and mineral processing works; SP1 is located between TP2 and TP3, and SP2 is located between TP2 and the *Paisana* stream.

All three tailings ponds, along with one of the two aforementioned mine galleries, was allowed to allow uncontrollable discharges into local streams. This circumstance led to frequent complaints being made against the company, which was accused of polluting the water in streams and, hence, the River Santa María (Gómez, 2008). There were also complaints by local inhabitants about deforestation and the pollution of soil, flora and fauna (Hughes-Ortega, 1998). Given this mechanical instability scenario of tailing points and the wet tropical climate in the area, there is a real possibility of an extreme climatic rainfall event causing tailing materials to enter the local hydrological system. Such a discharge would affect the soil and groundwater in the area and would, thus, increase pressure on the River Santa María and pose a risk for the peasant population living in the region and its surroundings, who engage in subsistence agriculture and livestock farming activities. Currently, the Panamanian government has plans to reactivate the Remance mining concession, which has led to protests by residents in the area against mining because they fear that the pollution history in the region will be repeated.

2.2. Sampling of tailings

Sampling was performed between May and June 2019 during the rainy season. The location map of the taken samples is presented in Fig. 1. The survey included 13 samples (seven from tailing ponds, six from secondary ponds and their surroundings) and one corresponding to the sediments from the mouth of a mine gallery, which actively released water to a local stream. Samples TP1 (2) corresponded to the surface samples (0–15 cm depth) taken from two locations in this accumulation of tailings; samples TP2 (3) corresponded to a single site, but at two depths (0–15 cm and 15–30 cm) near the SE border of this pond; samples TP3 (3) corresponded to two sites, with a surface sample (0–15 cm) and

two samples at different depths (0–15 cm and 15–30 cm); samples SP1 and SP2 included one taken from the button of each site and three samples from adjacent soils: one in SP1 (0–15 cm) and two in SP2 (at two depths, 0–15 and 15–30 cm). A reference sample was taken outside the mining area at the El Naranjal community, which located approximately 4 km away from the mining area.

Samples were collected with PVC tubes, which were jacked into the materials to obtain samples. The material was placed inside a plastic bag using a plastic shovel. The sediment samples (including those taken from the bottom of secondary ponds, which were flooded during sampling) were directly collected with a plastic shovel. Each sample was stored in a hermetic plastic bag, which contained approximately 3 kg of sample, to be stored at ambient temperature.

2.3. Laboratory analysis

Samples were taken to the laboratory, dried at ambient temperature, broken up with a wooden rolling pin and passed through a 2 mm sieve (Soiltest). The physicochemical analyses were conducted on the sieved sample, particularly pH, electrical conductivity (EC) and oxidation-reduction potential (ORP), which were determined in a 1:5 suspension (w/V) (ASTM D 4972) with a multiparameter benchtop Orion Versa Star Pro device. Moisture was determined by weight loss at 105 °C in an oven (P Selecta, 2000200) and on an OHAUS Adventurer Pro AV264C balance. Organic matter (OM) was established by weight loss at 455 °C (ASTM D 2974) in a Hobersal HD150 furnace. Cationic exchange capacity (CEC) was determined by the potentiometer method (Weaver et al., 1991). Colour when wet was measured by Munsell soil charts. The sample texture classification was assigned by the Unified Soil Classification System (USCS), which is a soil classification system employed in engineering and geology to describe the texture and size of the particles of a given soil. To classify soil, it is necessary to previously perform soil

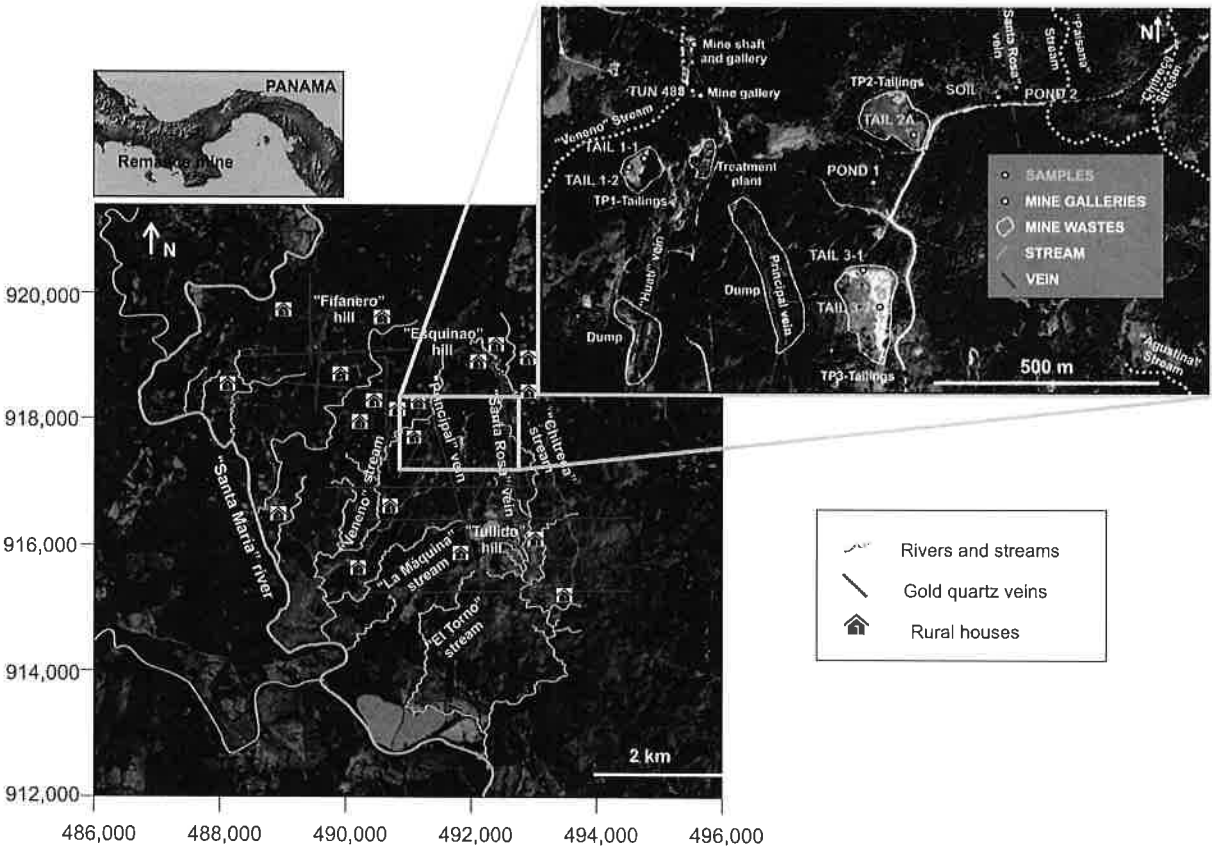


Fig. 1. Remance mine, locations of tailings, ponds and sites of samples collection.

granulometry by sieving. Then close to the Atterberg limits, the corresponding group was classified (ASTM D 2487) (ASTM, 2004). All the sieved samples were sent to Activations Laboratories Ltd. (Canada), where they were processed to determine total cyanide and PTEs. Metals were determined by partial digestion with aqua regia using a micro-processor hotbox to analyse pseudo-total concentrations (Melaku et al., 2005; Higuera et al., 2017). Extracts were measured by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) with certified reference materials Oreas 45 d and Oreas 520, which were also digested and analysed in triplicate. Recovery percentages were 90–100%. Total cyanide was measured by NaOH leaching for 16 h in the dark. A diluted portion of the solution was analysed by a SAN Plus Segmented Flow Analyzer. For the quality control, blanks, controls and duplicates were also analysed in all the analyses.

2.4. Methods

2.4.1. Pollution Index and Pollution Load Index

A site polluted by a certain element can be assessed by the Pollution Index (PI) (Equation (1)), and the same, but with more than one element, can be determined by the Pollution Load Index (PLI) (Tomlinson et al., 1980; Pan et al., 2019) using Equation (2).

$$PI = C_{soil} / C_{background} \tag{1}$$

$$PLI = (PI_1 \times PI_2 \times \dots \times PI_n)^{1/n} \tag{2}$$

where C_{soil} and $C_{background}$ are the concentrations of the particular PTE in the soil and background samples, respectively ($mg\ kg^{-1}$). The PLI is the Pollution Load Index of several elements, and the PI is the single Pollution Index for a certain element. Table 1 presents the evaluation criteria for both the PI and PLI (Pan et al., 2019).

2.4.2. Toxicity response coefficient and the potential Ecological Risk Index

Hakanson (1980) defined RI as an index that combines environmental effects and element toxicity to consider the general ecological migration and transformation trends of these elements in soils and sediments. Pan et al. (2019) defined the toxicity response coefficient (Er) as the single potential ecological risk for a certain element (Equation (3)), which is used to obtain RI (Equation (4)):

$$Er^i = PI \times Tr^i \tag{3}$$

$$RI = Er_1 + Er_2 + \dots + Er_n \tag{4}$$

where Er^i is the single RI, the PI is the single Pollution Index for a certain element and Tr^i is the toxicity response coefficient of element i . The Er calculation is based on Hakanson's element toxicity response coefficient standards (Hakanson, 1980), which can be given as follows: $Hg = 40$, $As = 10$, $Cu = 5$, $Zn = 1$, and $Sb = 7$ (Wang et al., 2018). Table 1 summarises the evaluation thresholds for these indices based on the respective proposers.

2.5. Statistical analysis

Microsoft Excel spreadsheets were used to manage the results and the programme Minitab 15 was employed to analyse the statistical parameters of the analytical results. A multivariate analysis was performed by applying a factor analysis and a principal component analysis (PCA). Both were applied to search for the influence of factors, or group of

factors, using “Varimax” orthogonal rotation. The map figure was generated with the Surfer 9 software and was edited in CorelDraw 2020 licensed by the UCLM.

3. Results

3.1. Total cyanide and correlations with edaphic parameters and PTEs

Regarding cyanide and its changes over time, the Remance gold mine, where the cyanidation process was used to extract Au and other precious metals during the last mining extraction (20 years ago since mining operations shut down), presented higher total cyanide values than those reported for uncontaminated sites in America ($<0.005\text{--}0.5\ mg\ kg^{-1}\ T\text{-CN}$) (Kjeldsen, 1999), which were similar to those reported in gold mine tailings at American sites ($1.5\text{--}23\ mg\ kg^{-1}\ T\text{-CN}$) (Kjeldsen, 1999) in TP1, TP2, mine gallery sediments, secondary ponds and nearby soil ($1.8, 1.6, 1.4, 1.9$ and $1.7\ mg\ kg^{-1}$, respectively). However, TP3 had higher T-CN values ($25.2\text{--}518.0\ mg\ kg^{-1}\ T\text{-CN}$) than these, and those reported in gold tailing 6, closed in Quebec, Canada ($4.8\ mg\ kg^{-1}\ T\text{-CN}$) (Zagury et al., 2004). A statistical analysis was performed to seek any correlations between pollution in the area and the presence of T-CN.

The description of the taken samples, together with their colour and texture characteristics, are presented in Table 2. The colour and texture of the samples in tailings 1 (TP1), tailings 2 (TP2) and tailings 3 (TP3) were the same: yellowish brown with mainly a silty sand texture. The sediments of secondary pond 1 (SP1) and secondary pond 2 (SP2) had the same silt texture, but different colours. The soil near SP1 was silt in texture and olive brown in colour, while the soil near SP2 was sandy silt in texture. The sediment in the mine gallery differed from the rest, with a

Table 2
Description of the taken samples, Munsell colour and USCS soil classification.

ID	Location/ Sample type	Depth (cm)	Munsell colour	Sample texture (USCS name group)
Tail 1-1	TP1/tailing	0–15	Yellowish brown, 10 YR 5/6	Silty sand
Tail 1-2	TP1/tailing	0–15	Yellowish brown, 10 YR 5/8	Silty sand
Tail 2 A	TP2/tailing	0–15	Yellowish brown, 10 YR 5/8	Silty sand
Tail 2 B	TP2/tailing	15–30	Yellowish brown, 10 YR 5/8	Silty sand
Tail 3-1 A	TP3/tailing	0–15	Yellowish brown, 10 YR 5/8	Silty sand with gravel
Tail 3- 1 B	TP3/tailing	15–30	Yellowish brown, 10 YR 6/8	Silty clayey sand
Tail 3-2	TP3/tailing	0–15	Yellowish brown, 10 YR 5/8	Silt with sand
Pond 1- sed	SP1/sediment	Surface	Light yellowish brown, 2.5 YR 6/4	Silt
Pond 1- T	Close to SP1/ soil	0–15	Olive brown, 2.5 Y 4/4	Silt
Pond 2- sed	SP2/sediment	Surface	Olive brown, 2.5 Y 4/4	Silt
Pond 2- T A	Close to SP2/ soil	0–15	Dark grey, 5 Y 4/1	Sandy silt with gravel
Pond 2- T B	Close to SP2/ soil	15–30	Dark brown, 7.5 YR 4/6	Sandy silt
Tun 488	Mine gallery/ sediment	Surface	Yellowish red, 5 YR 5/8	High plasticity clay

Table 1
Evaluation criteria for the Pollution Index (PI), the Pollution Load Index (PLI), the toxicity response coefficient (Er) and the Potential Ecological Risk Index (RI).

Index	Not polluted	Slightly polluted	Moderately polluted	Considerably polluted	Seriously polluted	Extremely polluted
PLI/PI	<1	1 < PLI < 2	2 < PLI < 3	PLI > 3	–	–
Er	<10	<40	40 < Er < 80	80 < Er < 160	160 < Er < 320	Er > 320
RI	<50	<150	150 < RI < 300	300 < RI < 600	600 < RI < 1200	RI > 1200

yellowish red colour and a high plasticity clay texture.

The average and standard deviation values of the physicochemical parameters and elements of interest are found in Table 3, while all of those obtained results appear in S1. The samples taken from each tailing, the sediment samples from secondary ponds, the soil samples close to SP1 and SP2, and the mine gallery sediments were grouped. Values of pH ranged between 3.9 and 5.0. The most acidic pH corresponded to the mine gallery sediments, and the highest, to the sediments of secondary ponds. The EC ranged between 0.03 and 0.52 dS m⁻¹, and TP1 and TP2 had the lowest value, with the highest value for the mine gallery sediments. The ORP values ranged from 281.5 to 686.7 mV, with the lowest in the sediments of secondary ponds and the highest in TP3. Humidity was between 14.0% and 63.9%, with the lowest value in TP1 and the highest in the mine gallery sediments. Organic matter ranged from 0.6 to 12.9%, with the lowest value in TP2 and the highest in the mine gallery sediments. CEC went from 3.5 to 10.9 cmol kg⁻¹, with the lowest in TP3 and the highest in the mine gallery sediments.

The Fe concentration varied between 1.0 and >30.0%, and that of As was between 25.0 and 5030.0 mg kg⁻¹, with the lowest values in the sediments of secondary ponds and the highest in the mine gallery sediments. The Au concentration varied from 29.9 to >1000.0 mg g⁻¹, and that of Cu, between 10.4 and 403.0 mg kg⁻¹, with the lowest values in the soils close to the secondary ponds and the highest in the mine gallery sediments. The Zn concentration ranged from 14.5 to 153.0 mg kg⁻¹; that of Co, from 0.9 to 13.7 mg kg⁻¹, and that of V, from 14.5 to 27.0 mg kg⁻¹, with the lowest values in TP2 and the highest in the mine gallery sediments. The average Ag concentration varied between 0.7 and 5.7 mg kg⁻¹, and that of Hg, between 0.6 and 1.4 mg kg⁻¹, with the lowest concentration in the soils near secondary ponds and the highest in TP3. The average total cyanide (T-CN) concentration varied from 1.4 to 187.9 mg kg⁻¹, and that of Pb, from 1.7 to 24.9 mg kg⁻¹, with the lowest concentration in the mine gallery sediments and the highest in TP3. The average Ba concentration ranged between 55.4 and 514.5 mg kg⁻¹, and that of Cr, between 2.0 and 6.5 mg kg⁻¹, with a low concentration in the mine gallery sediments and the highest in TP2. The Sb range went from 0.9 to 20.7 mg kg⁻¹, with a low concentration in the soils near secondary ponds and the highest concentrations in TP2. The gallery mine sediments corresponded to the sediments that left a tunnel located in the ‘Principal’ vein, where an underground water current flows and discharges into the ‘Veneno’ stream. TP3 corresponded to the last tailings used until 1999, when mining operations ceased. Although the use of secondary ponds is unclear, they may have acted as a stage prior to downloading in streams (González Valoys et al. 2021).

According to the Panama Soil Standard (Gaceta Oficial Digital, 2009) (Table 4), the soils near secondary ponds exceeded the limit that the standard sets out for industrial use for As, and also for residential use for Ba and Zn.

Although tailings are not soil, their behaviour with the climatic conditions is similar, and also they can favour the dispersion of pollutants to surrounding soils and water bodies (González-Valoys et al., 2021; Rodríguez-Hernández et al., 2021). This is why the study materials relating to mining operations were compared to a soil standard, either from Panama or Costa Rica (Table 4), which gave the following PTEs of interest: As, Hg, Ba, Zn (Gaceta Oficial Digital, 2009), Cu, Sb (Ministerio de Salud, 2010), for exceeding the limit for some agricultural, residential or industrial uses. Local residents employ tailings, one as a football ground (TP1) and another to graze animals on, e.g. horses (TP3). Hence the need to study and compare them to regulations, and to evaluate their degree of pollution and the ecological risk they pose.

3.2. Statistical analysis

Fig. 2 presents the multivariate PCA performed of the samples studied for the T-CN physicochemical parameters, the precious elements that were the object of the mining process (Au, Ag), Fe, and the PTEs of interest (Cu, Zn, As, Sb, Ba, Hg). According to the strengths of the

Table 3
Average values and standard deviations of the physicochemical parameters and PTEs (mg kg⁻¹) in the different material types in the sampled areas. Abbreviations: EC, electrical conductivity; ORP, oxidation reduction potential; OM, organic matter; CEC, cationic exchange capacity; T-CN, total cyanide.

Location	Sample type	pH	EC dS m ⁻¹	ORP mV	Humidity %	OM %	CEC cmol kg ⁻¹	Fe %	Au mg g ⁻¹	Ag mg kg ⁻¹	T-CN mg kg ⁻¹	As mg kg ⁻¹	Hg mg kg ⁻¹	Sb mg kg ⁻¹	Cu mg kg ⁻¹	Ba mg kg ⁻¹	Zn mg kg ⁻¹	Pb mg kg ⁻¹	Co mg kg ⁻¹	Cr mg kg ⁻¹	V mg kg ⁻¹
TP1	Tailing	4.5 ± 0.1	0.03 ± 0.01	612.6 ± 23.1	14.0 ± 4.9	0.8 ± 0.2	4.8 ± 0.2	3.4 ± 1.7	617.5 ± 190.2	1.2 ± 0.2	1.8 ± 0.1	658.0 ± 410.1	1.1 ± 0.7	18.4 ± 10.1	34.4 ± 17.1	407.0 ± 227.7	18.0 ± 8.5	13.4 ± 6.7	1.3 ± 0.1	3.5 ± 0.7	18.0 ± 4.2
		4.5 ± 0.1	0.03 ± 0.01	505.5 ± 76.3	14.5 ± 1.0	0.6 ± 0.1	4.5 ± 0.1	2.5 ± 0.2	507.0 ± 26.9	1.9 ± 0.3	1.6 ± 0.1	465.5 ± 37.5	1.0 ± 0.3	20.7 ± 2.5	21.5 ± 1.1	514.5 ± 135.1	14.5 ± 2.1	11.7 ± 1.6	0.9 ± 0.1	6.5 ± 0.7	14.5 ± 0.7
TP2	Tailing	4.5 ± 0.1	0.03 ± 0.01	505.5 ± 76.3	14.5 ± 1.0	0.6 ± 0.1	4.5 ± 0.1	2.5 ± 0.2	507.0 ± 26.9	1.9 ± 0.3	1.6 ± 0.1	465.5 ± 37.5	1.0 ± 0.3	20.7 ± 2.5	21.5 ± 1.1	514.5 ± 135.1	14.5 ± 2.1	11.7 ± 1.6	0.9 ± 0.1	6.5 ± 0.7	14.5 ± 0.7
		4.5 ± 0.1	0.03 ± 0.01	505.5 ± 76.3	14.5 ± 1.0	0.6 ± 0.1	4.5 ± 0.1	2.5 ± 0.2	507.0 ± 26.9	1.9 ± 0.3	1.6 ± 0.1	465.5 ± 37.5	1.0 ± 0.3	20.7 ± 2.5	21.5 ± 1.1	514.5 ± 135.1	14.5 ± 2.1	11.7 ± 1.6	0.9 ± 0.1	6.5 ± 0.7	14.5 ± 0.7
TP3	Tailing	4.5 ± 0.1	0.03 ± 0.01	505.5 ± 76.3	14.5 ± 1.0	0.6 ± 0.1	4.5 ± 0.1	2.5 ± 0.2	507.0 ± 26.9	1.9 ± 0.3	1.6 ± 0.1	465.5 ± 37.5	1.0 ± 0.3	20.7 ± 2.5	21.5 ± 1.1	514.5 ± 135.1	14.5 ± 2.1	11.7 ± 1.6	0.9 ± 0.1	6.5 ± 0.7	14.5 ± 0.7
		4.5 ± 0.1	0.03 ± 0.01	505.5 ± 76.3	14.5 ± 1.0	0.6 ± 0.1	4.5 ± 0.1	2.5 ± 0.2	507.0 ± 26.9	1.9 ± 0.3	1.6 ± 0.1	465.5 ± 37.5	1.0 ± 0.3	20.7 ± 2.5	21.5 ± 1.1	514.5 ± 135.1	14.5 ± 2.1	11.7 ± 1.6	0.9 ± 0.1	6.5 ± 0.7	14.5 ± 0.7
SP1, SP2	Sediment	5.0 ± 0.1	0.08 ± 0.03	281.5 ± 6.6	40.7 ± 8.4	5.4 ± 2.9	10.2 ± 2.1	1.0 ± 0.3	86.4 ± 53.2	0.4 ± 0.4	1.9 ± 0.1	25.0 ± 10.8	0.2 ± 0.1	1.7 ± 0.8	12.8 ± 10.4	298.5 ± 40.3	23.5 ± 2.1	7.4 ± 0.0	2.4 ± 2.7	2.0 ± 0.0	19.0 ± 1.4
		5.0 ± 0.1	0.08 ± 0.03	281.5 ± 6.6	40.7 ± 8.4	5.4 ± 2.9	10.2 ± 2.1	1.0 ± 0.3	86.4 ± 53.2	0.4 ± 0.4	1.9 ± 0.1	25.0 ± 10.8	0.2 ± 0.1	1.7 ± 0.8	12.8 ± 10.4	298.5 ± 40.3	23.5 ± 2.1	7.4 ± 0.0	2.4 ± 2.7	2.0 ± 0.0	19.0 ± 1.4
Soil close to SP1, SP2	Soil	4.8 ± 0.1	0.11 ± 0.06	453.8 ± 153.3	26.5 ± 8.1	5.3 ± 1.2	9.6 ± 0.3	2.3 ± 0.7	29.9 ± 19.3	0.1 ± 0.1	1.7 ± 0.2	56.0 ± 4.2	0.1 ± 0.1	0.9 ± 0.6	10.4 ± 4.3	196.3 ± 45.4	44.0 ± 23.4	5.5 ± 1.9	1.7 ± 1.1	2.7 ± 0.6	26.7 ± 8.5
		4.8 ± 0.1	0.11 ± 0.06	453.8 ± 153.3	26.5 ± 8.1	5.3 ± 1.2	9.6 ± 0.3	2.3 ± 0.7	29.9 ± 19.3	0.1 ± 0.1	1.7 ± 0.2	56.0 ± 4.2	0.1 ± 0.1	0.9 ± 0.6	10.4 ± 4.3	196.3 ± 45.4	44.0 ± 23.4	5.5 ± 1.9	1.7 ± 1.1	2.7 ± 0.6	26.7 ± 8.5
Mine gallery	Sediment	3.9 ± 0.1	0.52 ± 0.05	542.3 ± 54.2	63.9 ± 12.9	12.9 ± 1.4	10.9 ± 1.4	>30.0	>1000	0.7 ± 0.7	1.4 ± 1.4	5030.0 ± 5030.0	0.6 ± 0.6	2.2 ± 2.2	403.0 ± 403.0	55.4 ± 55.4	153.0 ± 153.0	1.7 ± 1.7	13.7 ± 13.7	2.0 ± 2.0	27.0 ± 27.0
		3.9 ± 0.1	0.52 ± 0.05	542.3 ± 54.2	63.9 ± 12.9	12.9 ± 1.4	10.9 ± 1.4	>30.0	>1000	0.7 ± 0.7	1.4 ± 1.4	5030.0 ± 5030.0	0.6 ± 0.6	2.2 ± 2.2	403.0 ± 403.0	55.4 ± 55.4	153.0 ± 153.0	1.7 ± 1.7	13.7 ± 13.7	2.0 ± 2.0	27.0 ± 27.0

Table 4
Soil guidelines for the PTEs for Panama and Costa Rica (all the values are expressed as mg kg⁻¹).

Soil Guidelines	Uses	Ag	As	Hg	Sb	Cu	Ba	Zn	Pb	Co	Cr	V	Reference
Panama Maximum permissible limits of soil contaminants for human health	Others (agricultural)		4	1.4			10	3			10		Gaceta Oficial Digital (2009)
	Residential		20	14			100	30			100		
	Industrial		30	140			1000	300			1000		
Costa Rica	Prevention Value	2	5	0.5	2	20	150	300	72	25	2	52	Ministerio de Salud (2010)
Intervention Value (Concentration above which there are potential direct or in direct risks for human health)	Agricultural	25	35	12	5	20	300	450	180	35	40	250	
	Residential	50	55	36	10	50	500	1000	300	65	270	250	
	Industrial	100	150	70	25	100	750	2000	400	90	270	250	

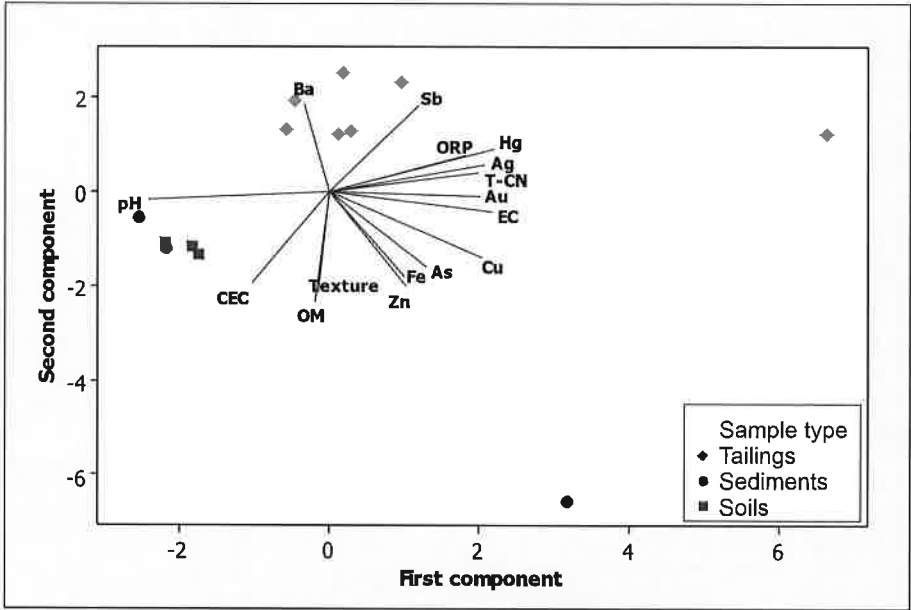


Fig. 2. PCA of the relations among T-CN, the main parameters and the PTEs concentrations. Generated with the data from tailings, sediments and soils.

relations (Table 5), the most significant relations were: for the first principal component (PC1), a positive relation was observed among T-CN (0.310), Ag (0.322), Cu (0.316), Au (0.313), Hg (0.343), EC (0.337) and ORP (0.282), and a negative relation to pH (−0.371). The second principal component (PC2) was positively related to Ba (0.316) and Sb (0.313), and negatively to OM (−0.396), texture (−0.364), Zn (−0.342), CEC (−0.330), Fe (−0.307) and As (−0.274).

Table 5
Principal component analysis matrix for the relation between T-CN (total cyanide) and the physicochemical parameters. Numbers in bold correspond to PC1 or PC2 and are more significant.

Variable	PC1	PC2
pH	−0.371	−0.026
EC	0.337	−0.075
ORP	0.282	0.130
OM	−0.028	−0.396
CEC	−0.157	−0.330
Fe	0.158	−0.307
Au	0.313	−0.016
Ag	0.322	0.096
T-CN	0.310	0.069
As	0.203	−0.274
Hg	0.343	0.153
Sb	0.184	0.313
Cu	0.316	−0.237
Ba	−0.049	0.316
Zn	0.159	−0.342
Texture	−0.021	−0.364

The PCA diagram also revealed how samples were grouped according to their nature, the tailings in the upper zone, the sediments of secondary ponds and the soils close to them on the left, and the mine gallery sediments far from the two previous groups (at the bottom) and to the right point Tail 3–2 of TP3, whose values were higher than the other tailings samples. This point had the highest T-CN concentration (518.0 mg kg⁻¹).

3.3. Pollution Index (PI) and Pollution Load Index (PLI)

Table 6 presents the PI and PLI values. According to the evaluation criteria for the PI and PLI in Table 1, the PI indicated considerable pollution (PI > 3) by T-CN, As, Hg, Sb and Cu, with the highest values in the tailings and the mine gallery sediments, followed in order of affection by secondary ponds and the soils near them. It is worth noting the very marked T-CN pollution that TP3 presented, and the mine gallery sediments with As.

The PLI came in the following order: TP3> mine gallery sediments > TP1> TP2> secondary pond sediments > soil close to secondary ponds. These findings indicated that the gallery mine and tailings were sources of pollution for the surrounding area.

3.4. Toxicity response coefficient (Er) and the potential Ecological Risk Index (RI)

The values calculated for Er and RI of Cu, Zn, As, Sb and Hg are shown in Table 7. According to the evaluation criteria in Table 1 for Er and toxicity according to each element, the Er values suggests that TP1,

Table 6
The average values and standard deviations of the Pollution Index (PI) and the Pollution Load Index (PLI) calculated for the different sample types.

	Sample type	PI T-CN	PI As	PI Hg	PI Sb	PI Cu	PI Ba	PI Zn	PLI
TP 1	Tailing	3.5 ± 0.1	35.4 ± 22.0	7.1 ± 4.7	61.2 ± 33.7	4.9 ± 2.4	1.7 ± 1.0	0.6 ± 0.3	6.0 ± 2.9
TP 2	Tailing	3.2 ± 0.3	25.0 ± 2.0	6.7 ± 1.7	68.8 ± 8.2	3.1 ± 0.2	2.2 ± 0.6	0.5 ± 0.1	5.3 ± 0.6
TP 3	Tailing	375.9 ± 571.7	34.0 ± 5.2	9.4 ± 10.5	50.6 ± 7.5	15.6 ± 19.8	1.3 ± 0.4	1.4 ± 0.2	12.6 ± 8.2
SP1, SP2	Sediment	3.7 ± 0.1	1.3 ± 0.6	1.4 ± 0.5	5.7 ± 2.8	1.8 ± 1.5	1.2 ± 0.2	0.8 ± 0.1	1.8 ± 0.4
Soil close to SP1, SP2	Soil	3.3 ± 0.3	3.0 ± 0.2	0.7 ± 0.3	3.1 ± 1.9	1.5 ± 0.6	0.8 ± 0.2	1.6 ± 0.8	1.6 ± 0.3
Mine gallery	Sediment	2.8	270.4	4.1	7.3	57.6	0.2	5.5	7.7

TP2 and TP3 pose a serious risk for their As, Hg and Sb contents, as well as mine gallery sediments, given their As, Hg and Cu contents. The extreme risk of the mine gallery sediments is highlighted for their high As content.

The average RI value presented the following order of potential ecological risk: mine gallery sediments (extreme risk); TP3, TP1, TP2 (serious risk); secondary pond sediments and nearby soils (considerable risk). This means that the gallery mine and tailings are sources of pollution for the surrounding area and represent a high ecological risk.

4. Discussion

Remance mine tailings still contain large amounts of PTEs and, together with the mine gallery sediments, they pose a risk as source of environmental pollution, given their total As, Cu, Sb, Ba, Hg and Zn contents, as verified by the presence of these PTEs in nearby soils and the sediments of the water network in the study area (González-Valoys et al., 2021). All these pollutants can cause several health problems: As can cause skin, liver and lung cancers; Cu can provoke abnormalities to the nervous system; Sb can harm the respiratory system; Ba can favor muscle paralysis; Hg produces neurological damage; Zn can weaken the immune system (Bini and Wahsha, 2014).

Although the T-CN concentrations found in most of the studied area fell within the ranges reported for gold mine tailings at American sites (Kjeldsen, 1999), T-CN at TP3 was higher than that reported in the literature for closed gold tailings in Canada (Zagury et al., 2004). Although we would expect cyanide to have evaporated as free cyanide 20 years after mining operations ceased, its concentrations should be similar to those in other areas, but it persists in TP3. The high T-CN concentration at TP3 did not seem to be linked with sample texture as the texture and colour of the three tailings were similar, and they also showed similar Fe, As, Hg and Sb concentrations. Nevertheless, the pH at TP3 was more acidic, both EC and ORP were higher, as were the Cu, Zn and Ag concentrations. The PCA showed a close relation between T-CN and Au, Ag, Hg and Cu, with which it would seem complexed and favoured by today's EC and ORP conditions. These cyanide complexes formed under certain conditions like sunlight and a strongly acidic medium slowly decompose (Meeussen et al., 1992; Anning et al., 2019) and are released to the environment, a phenomenon that has been reported by the study of Johnson et al. (2002), as photochemical changes in cyanide in tailing piles. The presence of T-CN and complexed cyanide was found in surrounding soils, stream sediments and the terrace sediments near the Remance mine tailings, while easily released cyanide was below the detection limit (González-Valoys et al., 2021), which demonstrates that cyanide complexes affect soils and water bodies, favoured

by the slope at the site and by runoff. All this suggests that the cyanides at TP1 and TP2 were treated after mining closed. However, high T-CN concentrations persist at TP3, which is the largest of the three and the last to be used, due to inappropriate abandonment and no residual cyanide decomposition.

In turn, T-CN is slowly released to the environment, and favours the release of other pollutants, such as Cu and Hg, with which it travels complexed. They have also been found in nearby soils, streams and terrace sediments (González-Valoys et al., 2021). Ba in the PCA analysis did not appear to be bound to T-CN, but to a second factor, Ba, which was inert, and could be bound due to its relations with Au–Sb in mineralisation as inert Ba.

The acidic pH at certain points like TP3 (pH 3.6), and the mine gallery sediments (pH 3.9), which are potential acid mine drainage (AMD) generators, could be due to their content of pyrite and marcasite (FeS₂), chalcopyrite (CuFeS₂) and arsenopyrite (FeAsS) minerals, as reported in the mining mineralogy by the company Remance S.A. (Nelson and Ganoza, 1999). AMD is produced as a result of abiotic and biotic reactions that involve water and air, and with sulphide minerals present in mine wastes (e.g., pyrite). These reactions produce acidic effluents that tend to be loaded with several heavy metals and metalloids (e.g., Fe, Cu, As, Hg) (Nadeif et al., 2019).

Arsenic came at high concentrations (5030.0 mg kg⁻¹) in the mine gallery sediments, and had to take an inorganic form after being released from minerals, such as arsenopyrite (FeAsS) from the 'Principal vein', from which the underground water stream came. The mine gallery sediments were characterised for their clay texture composition, acidic pH (3.9) and with high CEC (10.9). The high concentration of these PTEs (As, Cu, Zn) at this point could be associated with clay fractions, such as kaolinite and illite (Palansooriya et al., 2020), which were detected in the soil and sediment samples taken from streams near the area (González-Valoys et al., 2021), for which the best explanation would be the absorption/adsorption of PTEs by clays (González-Valoys et al., 2021).

The PI and PLI allowed a comparison to be made of the pollution level in an area to background areas. Thus the PI of T-CN showed marked pollution (PI > 3) in the tailings area and its surroundings, and TP3 obtained the highest value (PI 375.9) and, therefore, poses a source of pollution for the surroundings given its T-CN, As, Hg, Sb and Cu contents, which can have adverse health effects. For the PLI, TP3 was also the area with the highest pollution, followed by the mine gallery sediments, TP1 and TP2. This would be the order to be followed to recover areas in a recovery management plan for this area. To evaluate the possible effect of PTEs on the biota, the RI and Er were used, which complement information about the PLI. They revealed that the mine

Table 7
Average values and standard deviations of the toxicity response coefficient (Er) and the Potential Ecological Risk Index (RI) for the different sample types.

	Sample type	Er As	Er Hg	Er Sb	Er Cu	Er Zn	RI
TP 1	Tailing	353.8 ± 220.5	284.0 ± 186.7	428.2 ± 235.9	24.6 ± 12.2	0.6 ± 0.3	1091 ± 656
TP 2	Tailing	250.3 ± 20.1	266.7 ± 67.9	481.8 ± 57.7	15.3 ± 0.8	0.5 ± 0.1	1015 ± 145
TP 3	Tailing	340.3 ± 51.9	376.0 ± 421.0	353.9 ± 52.5	77.9 ± 98.9	1.4 ± 0.2	1150 ± 592
SP1, SP2	Sediment	13.4 ± 5.8	56.0 ± 18.9	39.7 ± 19.8	9.1 ± 7.4	0.8 ± 0.1	119 ± 40
Soil close to SP1, SP2	Soil	30.1 ± 2.2	29.3 ± 13.9	21.8 ± 13.5	7.4 ± 3.1	1.6 ± 0.8	90 ± 27
Mine gallery	Sediment	2704.3	165.3	51.3	287.9	5.5	3214

gallery sediments and tailings posed a serious ecological risk for the biota in this place, as well as a considerable ecological risk for the surrounding area.

Tailings with high Au and Ag contents must be reprocessed to extract the amount of remaining precious metals, which should then be properly remediated to avoid them becoming a source of pollution for the community via polluting soils, stream sediments and terrace sediments, which pose a risk for the ecology and human health of its inhabitants (González-Valoys et al., 2021). Longer-term remediation should be implemented using the measures proposed in the literature, such as chemical degradation of residual cyanide (Ebbs, 2004), covering tailing ponds (Henny et al., 1994) and the bioremediation (Viera and Stefenon, 2017) of not only surrounding soils, but also of stream sediments and sediments.

The problem of improperly abandoned mines is a latent problem in Panama and other countries. For this reason, there is a dire need to implement some type of economic surety for mining companies to raise funds with which to remedy the area if the company goes bankrupt. It is also necessary to reinforce measures to monitor proper compliance with environmental regulations and to promote scientific research in this field.

5. Conclusions

The tailings from the Remance gold mine and mine gallery sediments present a high degree of pollution given their PTEs (As, Hg, Sb, Cu) and T-CN contents. The highest PLI went to tailings 3, due to their high T-CN content. Hence, they represent a source of pollution for the surrounding areas and pose a serious ecological risk (RI) for the biota in this place.

Total cyanide content is similar to that of gold mine tailings at American sites in most of this area, but the last used tailings from mining operations contained a highest T-CN concentration. This clearly demonstrates that this pollutant persists more than 20 years after closing mining operations. This finding suggests that in later tailings, cyanide contents were not chemically treated before shutting down mining operations.

T-CN under certain specific pH, EC and ORP conditions is slowly released to the environment, which favours the release of other pollutants like Cu and Hg, with which it travels in a complexed manner. The pollutants that were also found in nearby soils, streams and terrace sediments also pose a risk to both the environment and human health of Remance community inhabitants (González-Valoys et al., 2021).

The Remance mine is an abandoned area with no environmental control. An environmental monitoring plan should be set up to avoid undesirable water, soil and plant uses by the local population. We recommend remediating the tailings ponds and mine works areas because they pose a serious environmental risk. We also recommend conducting bioavailability and bioaccessibility studies on these materials.

Declarations

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Code availability

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Authors' contributions

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Appendix A. Supplementary data

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An approach for evaluating the bioavailability and risk assessment of potentially toxic elements using edible and inedible plants—the Remance (Panama) mining area as a model

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Abstract Mining affects the environment, particularly through the persistence of accumulation of tailings materials; this is aggravated under tropical climatic conditions, which favours the release of potentially toxic elements (PTEs) bioavailable to the local flora and fauna and supposing a risk to human health. The Remance gold mine (Panamá), exploited intermittently for more than 100 years, and has remained derelict for over 20 years. Within the area live farmers who carry out subsistence agriculture and livestock activities. The objective of this study has

been to study the transference of PTEs in the local agricultural soil-plants system, with the goal of identifying their bioavailability to perform a human risk assessment. The results obtained of the Bioaccumulation coefficient in local plants show very weak to strong absorption of As (< 0.001 – 1.50), Hg (< 0.001 – 2.38), Sb (0.01 – 7.83), Cu (0.02 – 2.89), and Zn (0.06 – 5.32). In the case of Cu in grass (18.3 mg kg^{-1}) and plants (16.9 mg kg^{-1}) the concentrations exceed the maximum authorised value in animal nutrition for ruminants (10 mg kg^{-1}). The risk to human health for edible plants exceeds the non-carcinogenic risk for rice, corn, cassava, and tea leaves for Sb (HQ 19.450, 18.304, 6.075, 1.830, respectively), the carcinogenic risk for Cu

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($CR = 2.3 \times 10^{-3}$, 7.7×10^{-4} , 1.1×10^{-3} , 1.0×10^{-3} , respectively), and the carcinogenic risk for As in rice, corn and tea leaves ($CR = 8 \times 10^{-5}$, 3×10^{-5} , 3×10^{-5} , respectively). Urgent measures are needed to alleviate these effects.

Keywords Potentially toxic elements (PTEs) · Plants · Bioavailability · Risk assessment · Food

Introduction

Soil quality is affected by the presence of PTEs, which is largely due to anthropogenic activity (Bravo et al., 2017; Hooda, 2010; Rogival et al., 2007; Zhuang et al., 2009). Mining activity strongly impacts the environment because it implies exposing the minerals that contain PTEs to atmospheric conditions (Kamunda et al., 2016; Palansooriya et al., 2020). In particular, abandoned mining tailings become sources of environmental contamination (Chaabani et al., 2017; Kaninga et al., 2020; Santos et al., 2016) when they are exposed to environmental conditions like rain and wind, which influences the entire food chain from soils to plants and animals and, directly or indirectly, to human beings (Getaneh & Alemayehu, 2006).

For example, Cu is an essential micronutrient, which participates in the transfer of electrons, but it

can be toxic to plants and humans in large quantities (Bravo et al., 2015; Gómez-Armesto et al., 2015). Zn is linked with enzymes and participates in three plant functions: catalytic, coercive, and structural (Bravo et al., 2015). Ba is the trace element found at the highest concentrations in soil (Bravo et al., 2015), while Sb, As and Hg are non-essential trace elements. All these elements are named by Hooda, (2010) as PTEs, whose presence in soil poses a serious soil quality problem and a human health risk (Rascio and Navari-Izo, 2011; Sun et al., 2018).

The concentration of PTEs in plants depends on several factors, such as abundance and speciation ((bio)availability) in soil, type of plant and its age, depth of roots, among others (Cunha et al., 2014). The ability of plants to take up nutrients can be measured by the bioaccumulation coefficient (BAC), which is calculated as the ratios between the concentration of the element in a plant (any plant tissue, e.g., root, leaf, or fruit) and its content in soil (Kabata-Pendias, 2011; Cunha et al., 2014; Bravo et al., 2017), to observe the element's bioavailability in soil (Bravo et al., 2017). The bioaccumulation coefficient (BAC) applied to PTEs describes the transfer from soil to plants, while the bioconcentration coefficient (BC) describes a plant's ability to adsorb PTEs from soil when they appear in an available form (Gruszecka-Kosowska, 2020).

Many plants are used for direct human consumption as they form part of the population's diet, such as fruit and cereals. The human health risk posed by eating them as part of their daily diet can be assessed and determined by calculating the non-carcinogenic and carcinogenic risks of the PTEs they contain (Gruszecka-Kosowska, 2019, 2020). Eating plants can also affect human beings indirectly via ruminant animals because they form part of the food chain and can also affect ruminant animals' health (Aquilina et al., 2016; Pareja-Carrera et al., 2021).

According to the World Population Prospects, each state should promote its own research in relation to their agricultural regions and agroecosystems (UN, 2015). The National Secretary of Science and Technology (SENACYT) and the Institute for the Training and Use of Human Resources (IFARHU) of Panama promote a project in the abandoned Remance gold mine, where tailings are exposed to the climate conditions of wind and rain, which can affect surrounding soils and plants. The peasants who live

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within the old mine perimeter grow products for their own consumption and graze livestock, even in those areas very close to tailings. The objective of this study was to analyse the degree that mining activity affected flora in relation to the concentration of PTEs and their bioavailability by bearing in mind the human risk assessment and evaluating the health risk.

Materials and methods

Study area

The Remance gold mine is located in the village of Remance, a district of San Francisco, in the Veraguas province in the Republic of Panama, Central America. From a geological point of view, a hydrothermal alteration covers an area of some 10 km², and the epithermal gold deposit is hosted on a bed of pyroclastic rocks (Nelson & Ganoza, 1999). The gold deposit comprises a system of veins in which the principal vein contains the largest ore quantities, along with minor, but still relevant, veins like Santa Rosa and Consuelo, which are subterranean and have sporadic outcrops (Nelson & Ganoza, 1999).

The mine has been exploited intermittently by different companies for over 200 years, between 1800 and 1998. The last exploitation company was “Minera Remance S.A”, which operated the mine between 1989 and 1999 (Nelson & Ganoza, 1999) by applying the cyanidation process to extract precious metal (Gómez, 2008). Nowadays the mine is abandoned, and there are still three tailing ponds with mining waste exposed to environmental conditions, which could be sources of pollution for soils, water bodies, and flora (González-Valoys et al., 2021a).

According to the Köppen climate classification map, the climate in the study area corresponds to the Am type. It is a humid tropical climate, with the influence of monsoons, and an annual rainfall of > 2,250 mm that concentrates (60%) in the four wettest months (August–November). The rain rates of dry months (January–March) drop below 60 mm, and the average temperature of the coolest month is > 18 °C (Dirección de Meteorología de ETESA, 2007).

Pasture predominates in the old mine area, with stubble and shrubby vegetation no higher than 5 m and a few small mixed broadleaf forest patches. Some small settlements are found in the area, and the

commonest annual crops are rice, sugarcane, and corn (Ministerio de Ambiente Panamá, 2012), as well as other crops like cassava, banana, beans, among others. Cattle raising and horse grazing are also observed.

Sampling

Plant sampling was performed between May and June 2019, and in January 2020. Table 1 offers the collected samples, together with their common name, family, taxa and frequency for 75 samples, Table ST1 presents the coordinates. The location map of the samples appears in Fig. 1. The studied tissue was either leaves or edible plant parts. Together with each plant, a soil sample was collected to determine the BAC to evaluate the transfer of PTEs from soil to plants, and the available fraction was noted to evaluate the BC.

The edible part was taken from edible plants, while 30–40 leaves were collected from the rest of the plant as composite samples using gloves and scissors. Samples were placed in a paper envelope and stored at room temperature before being analysed. Soil samples were collected at 0–30 cm deep inside a PVC tube, which was placed inside soil to obtain samples (González-Valoys et al., 2021b). Soil samples (approx. 3 kg each) were placed in a plastic bag using a plastic shovel to be stored at ambient temperature.

Processing and analysing samples

Leaf samples were washed with deionised water to eliminate dust impurities, were left at ambient temperature for 4 days and then left to dry for 3 more days at 36 °C in a stove. Finally, samples were crushed by a domestic grinder to increase homogeneity. In the same way, soil samples were dried at ambient temperature, disaggregated with the help of a manual roller and sieved to less than 2 mm. The aliquots taken for the analysis (50 g) were further ground in an agate mortar until the diameter of the material was below 100 µm.

The elements Cu, Zn, As, Ba, Sb, and T-Hg were studied because in a previous study of the tailings from the abandoned gold mine, they are the PTEs that were above the value of the Panama soil standard (González-Valoys et al., 2021a). The Cu, Zn, As, Sb, and Ba determinations were made in both sample kinds, namely plants pressed into tablets and soil in a powder form, by energy dispersion X-ray fluorescence spectroscopy (ED-XRF) in Epsilon One equipment

Table 1 plant samples taken for the study. Edible plants in bold. The common names in italics are in Spanish

Family	Taxon	Common name	Frequency
Anacardiaceae	<i>Anacardium excelsum</i> (Bertero & Balb. ex Kunth) Skeels	<i>Espave'</i>	3
Annonaceae	<i>Xylopia frutescens</i> Aubl	<i>Malagueto macho</i>	4
Araceae	morphospecies	—	1
Araliaceae	<i>Schefflera morototoni</i> (Aubl.) Maguire, Steyerm. & Frodin	<i>Mangabe</i>	1
Asteraceae	<i>Baccharis trinervis</i> Pers	—	1
Asteraceae	<i>Ayapana stenolepis</i> (Steetz) R.M. King & H. Rob	<i>Tea leaves</i>	1
Bombacaceae	<i>Pseudobombax septenatum</i> (Jacq.) Dugand	<i>Barrigón</i>	2
Boraginaceae	<i>Heliotropium indicum</i> L	Turnsole, indian heliotrope	2
Burseraceae	<i>Bursera simaruba</i> (L.) Sarg	<i>Indio desnudo</i>	2
Clusiaceae	<i>Garcinia madruno</i> (Kunth) Hammel	<i>Satro</i>	1
Connaraceae	<i>Cnestidium rufescens</i> Planch	—	1
Convolvulaceae	<i>Ipomoea batatas</i> (L.) Lam	Yam or sweet potato	1
Cyperaceae	<i>Rhynchospora cephalotes</i> (L.) Vahl	Grass	2
Dennstaedtiaceae	<i>Pteridium caudatum</i> (L.) Maxon	Fern	2
Dilleniaceae	<i>Curatella americana</i> L	<i>Chumico</i>	4
Euphorbiaceae	<i>Mabea occidentalis</i> Benth	<i>Caciquillo</i>	2
Euphorbiaceae	<i>Manihot esculenta</i> Crantz	<i>Cassava, yuca</i>	1
Fabaceae-Mimosoideae	<i>Acacia mangium</i> Willd	<i>Acacia</i>	1
Fabaceae-Mimosoideae	<i>Acacia</i> sp.	<i>Acacia</i>	1
Fabaceae-Mimosoideae	<i>Calliandra magdalenae</i> (Bertero ex DC.) Benth	—	1
Fabaceae-Mimosoideae	<i>Cojoba rufescens</i> (Benth.) Britton & Rose	<i>Coralillo</i>	1
Fabaceae-Mimosoideae	<i>Zygia longifolia</i> (Humb. & Bonpl. ex Willd.) Britton & Rose	<i>Pichinde'</i>	1
Fabaceae-Papilionoideae	<i>Andira inermis</i> (W. Wright) Kunth ex DC	<i>Harino</i>	4
Gleicheniaceae	<i>Dicranopteris pectinata</i> (Willd.) Underw	Fern	1
Lauraceae	<i>Nectandra</i> sp.	<i>Sigua</i>	1
Lygodiaceae	<i>Lygodium venustum</i> Sw	<i>Crespillo</i>	2
Malpighiaceae	<i>Byrsonima crassifolia</i> (L.) Kunth	<i>Nance</i>	2
Malvaceae	<i>Guazuma ulmifolia</i> Lam	<i>Guácimo</i>	3
Malvaceae	mophospecies	—	3
Melastomataceae	<i>Miconia argentea</i> (Sw.) DC	<i>Papelillo</i>	1
Melastomataceae	<i>Mouriri myrtilloides</i> (Sw.) Poir		1
Moraceae	<i>Brosimum alicastrum</i> Sw	<i>Berba, cacique, breadnut</i>	1
Myrtaceae	<i>Eugenia</i> sp.	<i>Guayabillo</i>	1
Piperaceae	<i>Piper leptocladum</i> C. DC	<i>Cordoncillo</i>	1
Poaceae	morphospecies	Grass, <i>pasto</i>	12
Poaceae	<i>Oryza sativa</i> L	<i>Rice, arroz</i>	1
Poaceae	<i>Zea mays</i> L	<i>Corn, maíz</i>	1
Rubiaceae	<i>Alibertia edulis</i> (Rich.) A. Rich	Trumpet	1
Rubiaceae	<i>Declieuxia fruticosa</i> (Willd.) Kuntze	<i>Tea leaves</i>	1
Rubiaceae	<i>Genipa americana</i> L	<i>Jagua</i>	1
Sapindaceae	<i>Cupania americana</i> L	<i>Gorgojo, weevil</i>	1



Fig. 1 Location map of the plant samples taken within the Remance gold mine perimeter

(PANalytical brand). Total Hg (T-Hg) was determined by Zeeman atomic absorption spectroscopy with high-frequency modulation of light polarisation (ZAAS-HFM) using commercial equipment Lumex RA-915 M with a pyrolytic attachment (PYRO-915 +). Certified reference materials were used to check both precision and accuracy: NIST 2710A (Montana soil) and LGC7162 (strawberry leaves). Recovery percentages between 80 and 100% (ED-XRF) and 95–100% (ZAAS-HF) were obtained.

Based on high As and Cu concentrations determined by the ED-FRX analysis, a set of 12 soil samples was selected to evaluate the BC. In this way, the sequential extraction in three stages proposed by the European Community Bureau of Reference (BCR) was carried out in accordance with the procedure described by Sahuquillo et al., (1999): in step 1 (S1) the exchangeable and bound to carbonates fraction is extracted with acetic acid; in step 2 (S2) the reducible fraction (bound to Fe and Mn oxides), is extracted with hydroxylamine hydrochloride; and in step 3 (S3) the oxidizable fraction (bound to organic matter and sulphides) is extracted using a digestion with hydrogen peroxide first and then ammonium acetate. This method is widely used for evaluating the fractionation of metals and has been applied to study a wide variety of solid samples, including different mining waste types (Marguí et al., 2006; García-Ordiales et al., 2019). Hence, the first three fractions were considered

potentially labile or reactive fraction plant uptake or bioaccessible to humans (Kelepertzis & Stathopoulou, 2013; Madrid et al., 2007).

Measurements of Cu and As in the BCR extracts were taken by high-resolution atomic absorption spectroscopy (HR-AAS) in ContrAA-800 equipment (Analytik Jena brand) using the flame and the graphite furnace techniques, respectively. Samples were also subjected to microwave-assisted acid digestion with aqua regia according to EPA method 3051A (USEPA, 2007) to analyse pseudo-total concentrations (Higuera et al., 2017; Melaku et al., 2005). In all cases, solutions were filtered with Whatman filters (8 µm). As a quality control of total contents, analyses of blanks and random duplicates were performed. Certified reference material NIST 2710A was also digested and analysed in triplicate, with 95% and 98% recovery for Cu and As, respectively. Blanks and certified reference material BCR 701 were also used in the BCR extractions with recoveries between 95 and 102% for Cu (As is not certificated in this reference material).

Soil to plant transfer indices

Two indices were used to determine the transfer of PTEs from soil to plant: BAC and BC. The BAC is a key component for quantifying differences in metal bioavailability by describing the transfer of PTEs from

soil to plant (Gruszecka-Kosowska, 2019; Inacio et al., 2014). The ratios between the concentration of the element in the plant and the element concentration in soil was calculated (Bravo et al., 2015; Kabata-Pendias, 2011).

$$BAC = C_{\text{leaves or edible part plant}}/C_{\text{soil}}$$

where $C_{\text{leaves or edible part plant}}$ is the concentration of a particular PTE (mg kg^{-1}) in the leaves or edible part of the plant, and C_{soil} is the total concentration of a particular PTE in soil samples (mg kg^{-1}).

Bioconcentration coefficient (BC): describes the plant's capacity to adsorb PTEs from soil when PTEs appear in an available form (Gruszecka-Kosowska, 2019; Inacio et al., 2014). BC is calculated as the ratios between the PTE concentration in leaves or edible parts and the available concentrations of PTE in soil (Wang et al., 2006):

$$BC = C_{\text{leaves or edible part plant}}/C_{\text{soil available}}$$

where $C_{\text{leaves or edible part plant}}$ is the concentration of a particular PTE (mg kg^{-1}) in the leaves or the edible part plant and $C_{\text{soil available}}$ is the concentration of a particular PTE in soil samples (mg kg^{-1}) obtained from the BCR three-stage sequential extraction procedure because it is considered potentially labile or the reactive fraction plant uptake (Kelepertzis & Stathopoulou, 2013; Madrid et al., 2007).

Human health risk assessment

This assessment was performed by the following parameters: daily intake rate (DIR), average daily dose (ADD), hazard quotient (HQ), and carcinogenic risk (CR).

Daily intake rate (DIR) was calculated as the sum of consumed food (Gruszecka-Kosowska, 2019; WHO, 2005) which, in this case, included rice (grain), corn (grain), cassava (tuber), and tea leaves.

$$DIR = \sum (C_{\text{food}} \times IR_{\text{food}}/BW)$$

where C_{food} is the concentration of a particular PTE in food (rice, corn, cassava, tea leaves) (mg kg^{-1}), IR is the ingestion rate ($\text{g person}^{-1} \text{ day}^{-1}$) in food and BW is body weight (70 kg for adults) (USEPA, 2011). Table 2 presents the IR values used to calculate the DIR for an adult and corresponds to: the IR value of Panama as reported in a consultancy by the FAO (Kennedy et al., 2021) for rice; the minimum value for America (García-Casal et al., 2018) for corn considering that Panama consumes corn-based products to a lesser extent than the rest of Central America; the values reported in Nigeria (Afolami et al., 2020) for cassava; an average value reported for Pakistan (commercial black tea brands) (Idrees et al., 2020), and China (tea leaves)(Zhang et al., 2018). Here "teas" are taken to correspond to the herbs used locally for infusions (*Ayapana stenolepis* and *Declieuxia fruticosa*).

The ADD was calculated as the sum of the consumed food (Gruszecka-Kosowska, 2019; USEPA, 1989):

$$ADD = \sum (C_{\text{food}} \times IR_{\text{food}} \times EF \times ED \times 10^{-3}) / AT \times BW$$

where C_{food} is the PTE concentration in the investigated food (mg kg^{-1}), IR_{food} is the intake rate of cereals ($\text{g person}^{-1} \text{ day}^{-1}$), EF is exposure frequency: 365 d y^{-1} , ED is exposure duration with 30 y for adults (USEPA, 2011), AT is the average time in days with $ED \times 365$ for non-carcinogens, and $70 \text{ y} \times 365$ for carcinogens (Gruszecka-Kosowska, 2019; USEPA, 2001), BW is body weight (70 kg) and 10^{-3} is a unit conversion factor.

The non-carcinogenic risk represents the risk of daily exposure to PTEs (Gruszecka-Kosowska, 2019). The HQ is the non CR, where a value of 1 refers to the threshold reference value as suggested by the US Environmental Protection Agency (Pan et al., 2019), and is calculated as follows (USEPA, 1989):

Table 2 The IR values for different types of edible plants

Type of plant	IR ($\text{g person}^{-1} \text{ day}^{-1}$)	Reference
Rice, grain	125.2	Kennedy et al., (2021)
Corn, grain	50.0	García-Casal et al., (2018)
Cassava, tuber	42.0	Afolami et al., (2020)
Tea leaves	10.9	Idrees et al., (2020)/ Zhang et al., (2018)

Table 3 The RfD value of the non-carcinogenic elements and the SF for carcinogenic elements

Element	RfD (mg kg ⁻¹ d ⁻¹)	SF (mg kg ⁻¹ d ⁻¹)
Cu	4.0 × 10 ⁻²	1.5
Zn	3.0 × 10 ⁻¹	
As	3.0 × 10 ⁻⁴	
Sb	4.0 × 10 ⁻⁴	
Ba	2.0 × 10 ⁻¹	
Hg	3.0 × 10 ⁻⁴	

$HQ = ADD/RfD$

where HQ is the hazard quotient and RfD is the reference dose for a particular PTE. The RfD values for the PTEs (USEPA, 2019) in this study are presented in Table 3. The total non CR (HQ_t) value for the investigated PTEs was calculated as so (USEPA, 1989)

$HQ_t = HQ_1 + HQ_2 + \dots + HQ_n$

where HQ are the hazard quotient values for the 1-n PTEs herein investigated.

The CR values of the PTEs from dietary exposure were calculated by the formula (Gruszecka-Kosowska, 2019; USEPA, 1989):

$CR = ADD \times SF$

where CR is carcinogenic risk and SF is the oral slope factor over a lifetime for a particular PTE. The SF plays a key role being that the daily toxin intake results in an incremental risk of an individual developing cancer (Pan et al., 2019). Table 3 presents the SF values for the carcinogenic elements (Pan et al., 2019) in this study. The total CR value appears as the sum of the partial CR values (USEPA, 1989).

$CR_t = CR_1 + CR_2 + \dots + CR_n$

where CR are the carcinogenic risk values for the 1-n PTEs herein investigated.

Statistical analyses

Microsoft Excel spreadsheets were used to manage the results. Minitab 15 was employed to analyse the statistical parameters of the analytical results.

Results

PTEs and BAC

The synthetic statistical parameters for the group of samples are provided in Table 4 and SF1, all the obtained results for plants are expressed in ST2. The Cu concentrations in plant leaves varied between 4.3 and 57.3 mg kg⁻¹, while the BAC values indicated that Cu absorption was a weak to strong absorption accumulation in plants. It was remarkable that *Xylopia frutescens Aubl* was the species with the highest accumulation. The Zn concentrations in plant leaves were between 5.7 and 273.1 mg kg⁻¹, while the BAC values indicated that Zn absorption went from weak to strong absorption accumulation in plants. In this case, *Araceae morphospecies* was the plant taxon with the most accumulation. The As concentrations in plant leaves were between < 0.1 and 54.5 mg kg⁻¹, while the BAC values indicated very weak to strong absorption accumulation. The taxon with the most accumulation was *Poaceae morphospecies*. The Sb concentrations in plant leaves were between < 1.0 and 9.7 mg kg⁻¹, while the BAC values denoted a weak absorption to strong accumulation, with *Declieuxia fruticosa* (Willd) Kuntze being the species with the most accumulation. The Ba concentrations in plant leaves went from < 5.0 to 319.9 mg kg⁻¹, and BACs indicated very weak to moderate absorption. The Hg concentrations in leaves were between < 0.1 and 191.2 ng g⁻¹, while the BAC values indicated a very weak absorption to strong accumulation, with *Anacardium excelsum (Bertero & Balb. ex Kunth) Skeels* being the taxon with the highest accumulation rate for these elements. All the plants herein indicated with maximum concentrations corresponded to non-edible plants.

Table 5 is a compendium of the Cu, Zn, As, Sb, Ba, and Cu concentrations in plants from different countries around the world in both uncontaminated and contaminated areas to compare these values to those obtained at the Remance gold mine for edible products like rice (grain), corn (grain), cassava (tuber), tea leaves (medicinal plants), grass (leaves), and plants in general (leaves).

For rice, the average Cu concentration value at Remance (5.2 mg kg⁻¹) was slightly higher than that reported by Kabata-Pendias (2011) for contaminated sites (4.0 mg kg⁻¹), while the As contents

Table 4 Value of the PTEs in leaves and soils for Cu, Zn, As, Sb, and Ba expressed as mg kg⁻¹, Hg in ng g⁻¹ and BAC per element

Element	Range plant	Mean plant	Stand. dev. Plant	Range soil*	Mean soil*	Stand. dev. soil*	Range BAC	Mean BAC	Stand. dev. BAC	Description	Plant with most accumulation or absorption
Cu	4.3–57.3	16.9	9.6	5.4–396.9	70.3	61.1	0.02–2.89	0.46	0.47	Weak absorption to strong accumulation	<i>Xylopia frutescens</i> Aubl
Zn	5.7–273.1	31.1	34.9	12.0–166.1	54.4	27.5	0.06–5.32	0.7	0.75	Weak absorption to strong accumulation	<i>Araceae morphospecies</i>
As	< 0.1–54.5	2.4	9.4	< 0.8–714.5	110.6	171	< 0.001–1.50	0.06	0.21	Very weak absorption to strong accumulation	<i>Poaceae morphospecies</i>
Sb	< 1.0–9.7	3.5	1.8	< 0.6–41.8	16.1	6.3	0.01–7.83	0.48	1.15	Weak absorption to strong accumulation	<i>Declieuxia fruticosa</i> (Willd.) Kuntze
Ba	< 5.0–319.9	31.1	45	40.0–743.2	310.9	166.8	< 0.001–0.93	0.14	0.2	Very weak to moderate absorption	<i>Anacardium excelsum</i> (Bertero & Balb. ex Kunth) Skeels
Hg	< 0.1–191.2	18.5	29.5	< 5.0–6470.0	276.1	797.7	< 0.001–2.38	0.27	0.42	very weak absorption to strong accumulation	<i>Anacardium excelsum</i> (Bertero & Balb. ex Kunth) Skeels

*Values of the PTEs in soil taken from González-Valoys et al., (2021b)

Table 5 Comparative table of the uncontaminated and contaminated sites in several countries for rice, corn, cassava, tea leaves, grass, and plants in general; in relation to the concentration of potentially toxic elements (Cu, Zn, As, Sb, Ba, and Hg in mg kg⁻¹)

Plant	Site	Cu	Zn	As	Sb	Ba	Hg	Reference
Rice, grains	Uncontaminated sites-different countries		18.0	< 0.1				Kabata-Pendias, 2011
	Agricultural soils-China	2.7	18.0				0.004	Rothenberg et al., 2011
	Agricultural soils-Italy	4.8	24.6	< 0.1	1.1	9.3		Nadimi-Goki et al., 2014
	Agricultural soils-Sri Lanka	2.2	15.5	0.1				Rajatheja et al., 2021
	Contaminated site-different countries	4.0		1.2			4.900	Kabata-Pendias, 2011
	Remance mining area-Panama	5.2	17.9	0.2	4.4	12.1	< 0.001	This work
Corn, grains	Uncontaminated sites-different countries		30.5	1.8	< 2.0		0.037	Kabata-Pendias, 2011
	Agricultural soils-Brazil	1.7	17.5	< 0.1		2.7	< 0.030	Yada et al., 2020
	Agricultural soils-Poland	0.5	7.4	< 0.1	< 0.1		0.002	Gruszecka-Kosowska, 2020
	Agricultural soils-Czech Republic	1.4	6.5					Adaev et al, 2021
	Industrial area-Greece	2.3	16.0	0.2	0.4			Antoniadis et al., 2019
	Coal mining-contaminated soil-China	1.7	22.7			6.1		Hussain et al., 2019
	Contaminated site-different countries						0.105	Kabata-Pendias, 2011
	Remance mining area-Panama	4.3	22.0	0.2	4.7	11.7	< 0.001	This work
Cassava, tuber	Agricultural soils-Ghana		7.4					Danso et al., 2001
	Agricultural soils-Nigeria	11.2	< 0.1					Adejumo et al., 2019
	Remance mining area-Panama	7.5	9.0	< 0.1	4.1	18.5	< 0.001	This work
Tea, leaves	Uncontaminated sites-different countries	20.0					0.040	Kabata-Pendias, 2011
	Black tea-Pakistan	8.9	1.4					Idrees et al., 2020
	Remance mining area-Panama	19.2	88.8	0.6	4.7	35.5	0.002	This work
Grass, leaves	Uncontaminated sites-different countries	6.0	31.5	2.8				Kabata-Pendias, 2011
	Uncontaminated sites-Russia	14.6	47.4	< 0.1				Shtangeeva et al., 2020a, 2020b
	Uncontaminated sites-Russia	12.6	37.0	0.2	0.1	7.3		Shtangeeva et al., 2020a, 2020b
	Contaminated sites-different countries	42.0		31.2				Kabata-Pendias, 2011
	Coal mining-contaminated soil-China	18.5	86.4			41.4		Hussain et al., 2019
	Remance mining area-Panama	18.3	27.3	5.5	3.0	13.7	0.019	This work

Table 5 continued

Plant	Site	Cu	Zn	As	Sb	Ba	Hg	Reference
Different types of plant leaves	Uncontaminated sites-different countries					7.5		Kabata-Pendias, 2011
	Uncontaminated sites-Russia	15.0	34.2	0.1				Shtangeeva et al., 2020a, 2020b
	Uncontaminated sites-Russia	9.2	50.0	0.2	0.1	19.0		Shtangeeva et al., 2020a, 2020b
	Coal mining-contaminated soil-China	7.1	43.1			25.4		Hussain et al., 2019
	Gold mining-Ethiopia	36.9	96.0	8.8	0.3			Getaneh & Alemayehu, 2006
	Remance mining area-Panama	16.9	31.1	3.4	3.9	36.5	0.021	This work

(0.2 mg kg⁻¹) were higher than the value for uncontaminated sites (0.005 mg kg⁻¹) but lower than the reference level for contaminated sites (1.2 mg kg⁻¹) (Kabata-Pendias, 2011). The concentrations of Sb (4.4 mg kg⁻¹) and Ba (12.1 mg kg⁻¹) were higher than those reported in agricultural soils in Italy (1.1 mg kg⁻¹, 9.3 mg kg⁻¹, respectively) (Nadimi-Goki et al., 2014). The average value of the Zn concentrations (17.9 mg kg⁻¹) was similar to the values reported for uncontaminated sites (18.0 mg kg⁻¹) (Kabata-Pendias, 2011) and in agricultural areas (15.5–24.6 mg kg⁻¹) (Nadimi-Goki et al., 2014; Rajatheja et al., 2021; Rothenberg et al., 2011). Finally, the Hg concentrations were lower than the detection limit (< 0.001 mg kg⁻¹).

For corn, Cu, Zn, As, Sb, and Ba were higher than in agricultural soils (Adaev et al., 2021; Gruszecka-Kosowska, 2020), while Zn was higher than cassava in agricultural soils (Danso et al., 2001). In tea leaves, the average Cu concentration fell within the same range as in uncontaminated areas (Kabata-Pendias, 2011), and Zn concentrations were much higher than those reported for commercial tea by Idrees et al (2020). In grass and plants, Cu, As, Sb, and Ba were higher than in the uncontaminated sites reported by Shtangeeva et al., (2020a, b).

Statistical analysis

Figure 2 presents the dendrogram for the PTEs studied in Remance plant leaves and ST3 presents Pearson's correlation. Pearson's correlation showed that Cu was significantly related to Zn, meanwhile, As was related

both to Ba and Hg, and Ba appears to be related to Hg. After a multivariate analysis, the relation among these six PTEs is displayed in the dendrogram of Fig. 2. This statistical approach clearly separated PTEs into two subgroups: one with Cu and Zn, and another including As, Hg, Ba, and Sb.

Transfer of PTEs from soils to plants

Figure 3 shows a combined graph of the percentages taken in each step of the BCR sequential extraction for Cu and As, respectively. The total extracted PTEs are displayed in ST3. It is possible to consider the first three BCR steps (S1 + S2 + S3) to be the fractions, including the potentially labile or reactive species, while the residual fraction can be taken as unavailable for transport, plant uptake, or as bioaccessible to humans (Madrid et al., 2007; Kelepertzis et al., 2013). The first fraction corresponds to the water-soluble fraction, which is easily exchangeable and interpreted as the most mobile and bioavailable for the environment (Pérez-López et al., 2008). Fraction 2 (metals bound to oxides Fe and Mn) and fraction 3 (complexed with sulphides and organic matter) can be mobilised under increasing reducing or oxidising conditions, respectively (Kelepertzis et al., 2013). For Cu, fractions 1, 2 and 3 averaged 4.45, 9.15 and 4.34%, respectively, with an average total labile fraction of 17.94% and fraction 2 with the highest contribution (Fig. 3). For As, fractions 1, 2 and 3 averaged 0.04, 0.40 and 1.39%, respectively, with an average total labile fraction of 1.82% and fraction 3 with the highest contribution (Fig. 3).

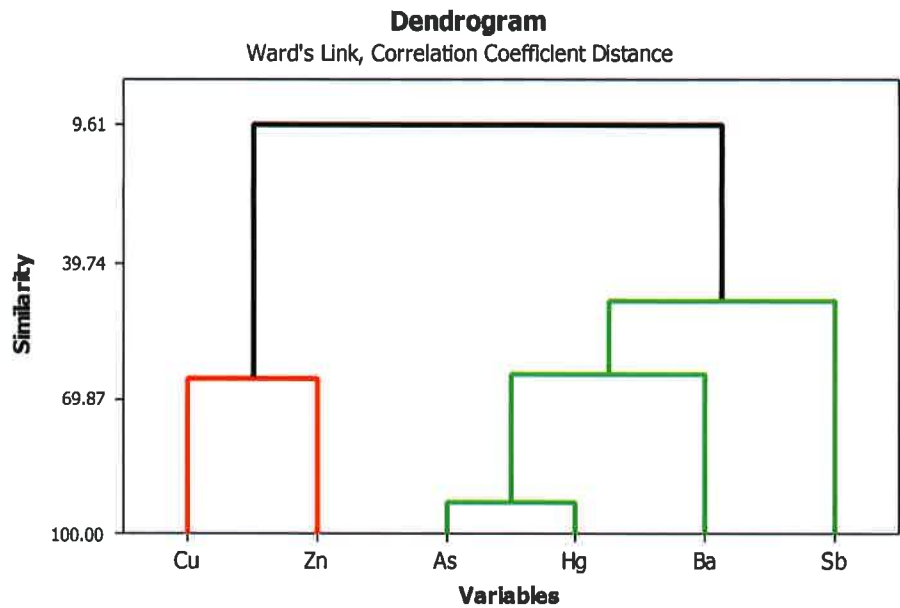


Fig. 2 Dendrogram shows results of cluster analysis (Ward’s method) and linkage distance between parameters of the PTEs found in the leaves samples

Table ST4 presents the BAC and BC for a group of samples with high As and Cu contents in soil. These coefficients were used to evaluate the bioavailability of PTEs, and the plant’s capacity to bioaccumulate Cu and As and to bioconcentrate their available fractions. Figure 4 shows a bar graph to compare the fraction available in soil (obtained by BCR) and the concentration in the leaves of plants for Cu and As. Cu is seen as an essential element for plants and appears as being more available in soil (BCR), while plants show good uptake capacity and often high accumulation rates (average BC 3.97). As, which is scarcely available in most soils (mean BC: 0.88), also has lower uptake rates.

Figure 5a shows the correlation detected by Pearson’s test between the Cu concentration in plants and the Cu fraction available in soil, which is weakly negative. Figure 5c shows the relation between the As concentration in plants and the As fraction available in soil. No clear correlation is noted, albeit a very weakly positive one, which seems to be dominated by having low As absorption concentrations available in soil. Figures 5b and d show the positive and closer relationship between the BAC and BC indices for Cu and As, respectively.

Human health risk assessment

Daily intake rates

Table 6 shows the DIR values of PTEs for the edible products obtained from the Remance gold mine. The inhabitants’ diet is based on products like rice, corn, or cassava, which are produced locally and consumed daily, with tea leaves consumed sporadically as medicinal tea. The DIR values of each edible product are compared to the provisional maximum tolerable daily intakes (PMTDI) ($\text{mg kg}^{-1} \text{ bw day}^{-1}$) (Gruszecka-Kosowska, 2020) as so: Cu 0.5 (FAO/WHO, 2001), Zn 1 (FAO/WHO, 2001), As 0.0021 (FAO/WHO, 1989), Sb 0.006 (WHO, 2008), Ba 0.02 (EU, 2012), Hg 0.0006 (FAO/WHO, 2011). The values of Cu DIR (2.024 to 9.301), Zn DIR (5.370 to 32.015), Sb DIR (0.716 to 7.780), and Ba DIR (4.562 to 21.642) exceeds the PMTDI in all foods, while As DIR (0.078 to 0.268) exceeds in food, except for cassava, and the Hg DIR is only marked in tea leaves (0.0008 to 0.0028) and exceeds the PTMDI.

The non-carcinogenic risk of PTEs

The non CR of PTEs was evaluated with the HQ, which was set at 1 (USEPA, 1989). Values exceeding 1 were

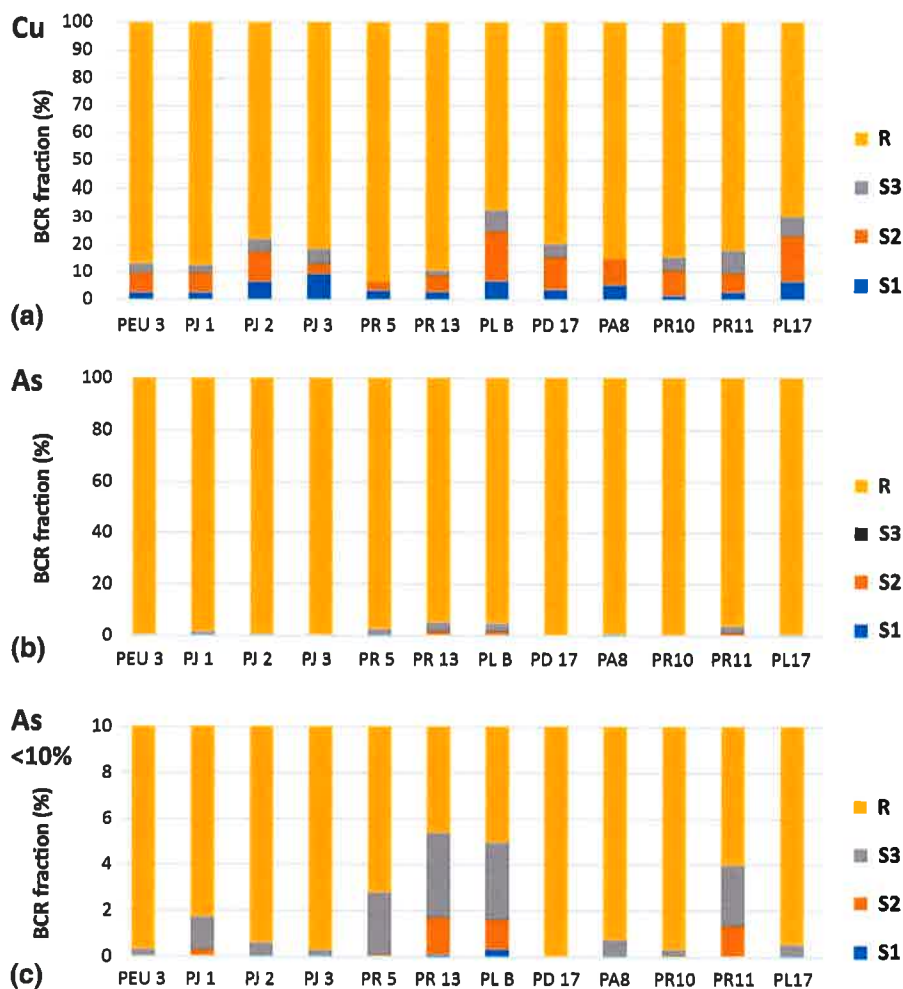


Fig. 3 Combined bar graph for the BCR fractions and the residual in the plant-associated soil samples. **a** Cu fraction. **b** As fraction. **c** Detail of the fraction of As less than 10%

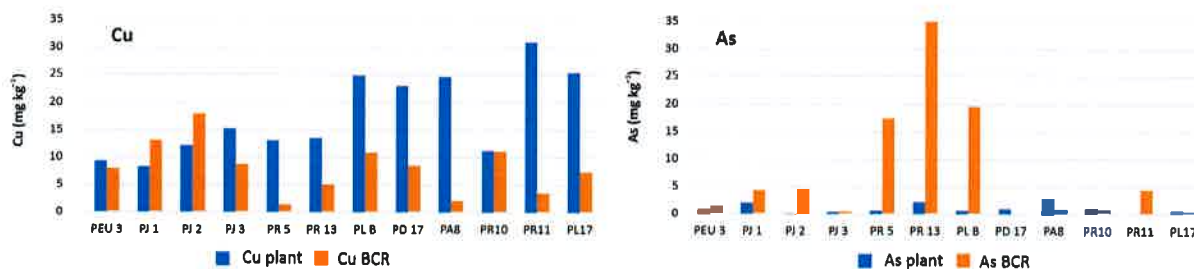


Fig. 4 Bar graph comparing Cu and As concentration in leaves and available fraction (BCR S1 + S2 + S3)

considered a non CR. Figure 6a shows the HQ for the PTEs of the studied edible plant and ST5 values. As we can see, the HQ value was exceeded by Sb in them all and in this order: rice > corn > cassava > tea leaves (19.451 > 18.304 > 6.075 > 1.830). Cu, Zn, As, Ba,

and Hg did not exceed the value of 1 for HQ. The total HQ value (sum of the HQ for PTEs) of all the edible plants exceeded 1, which means that it represents a non CR.

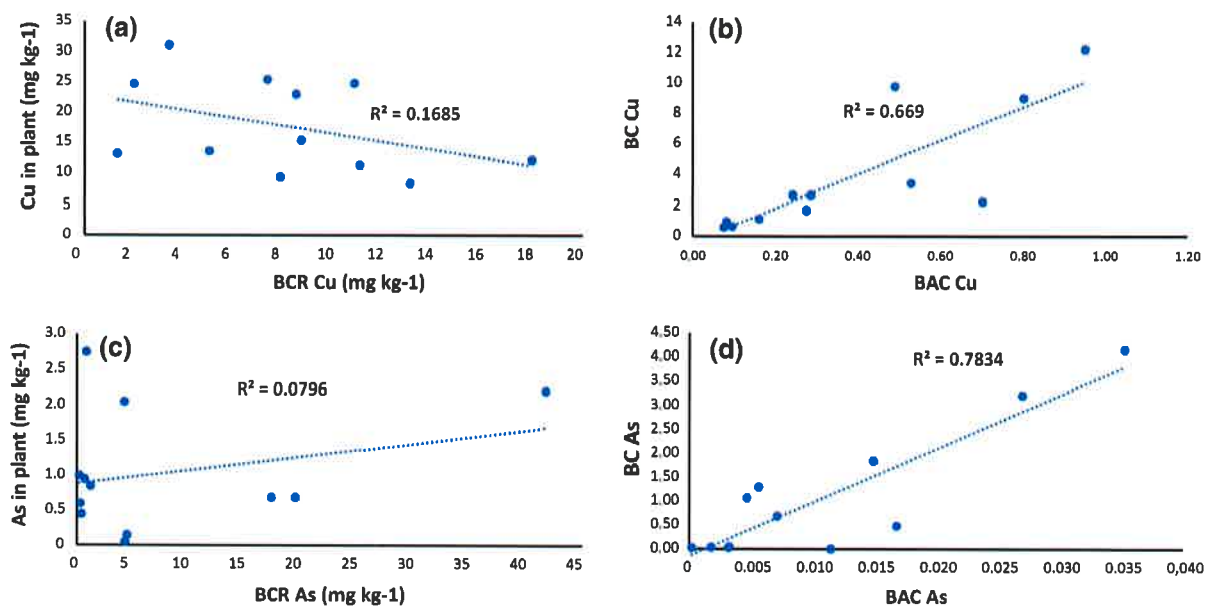


Fig. 5 **a** Cu concentration in the plant vs available Cu concentration in soil (BCR). **b** Bioconcentration and bioaccumulation of Cu in the plant. **c** As concentration in the plant vs available As concentration in soil (BCR). **d** Bioconcentration and bioaccumulation of As in the plant

Table 6 The DIR (mg kg⁻¹ day⁻¹), values of PTEs for the food products obtained from the Remance gold mine

Edible plants	ID	DIR Cu	DIR Zn	DIR As	DIR Sb	DIR Ba	DIR Hg
Rice, grain	PR15	9.301	32.015	0.268	7.780	21.64	0.00009*
Corn, grain	PR16	3.036	15.679	0.107	3.321	8.36	0.00004*
Cassava, tuber	PR8	4.470	5.370	0.030*	2.430	11.10	0.00003*
Tea leaves	PM1	2.024	8.074	0.101	0.732	4.56	0.00078
Tea leaves	PM4	3.963	19.550	0.078	0.716	6.49	0.00280
PMTDI		0.500	1.000	0.002	0.006	0.02	0.00060

PMTDI: provisional maximum tolerable daily intakes (mg kg⁻¹ day⁻¹)

*Calculations use the half of the detection limit

The carcinogenic risk of PTEs

The acceptable CR risk level was set to equal 1×10^{-6} for an individual PTE and to equal 1×10^{-4} for the sum of carcinogenic PTEs (USEPA, 1989). Values exceeding this are considered a CR. Figure 6b shows the CR for Cu and Fig. 6c for As and the ST5 includes the complete values. The acceptable CR value is exceeded by As in rice (7.67×10^{-5}), corn (3.06×10^{-5}) and tea leaves (2.22×10^{-5} to 2.89×10^{-5}). Excess Cu was obtained in all the edible plants (5.10×10^{-4} to 2.34×10^{-3}) in this

order: rice > cassava > tea leaves > corn. This is the same order for the total CR.

Animal nutrition for ruminants

In the Remance mining area and its surroundings, peasants perform subsistence livestock work and graze horses. The mean Cu value in grass (*Poaceae morphospecies*) was 18.3 mg kg⁻¹ and was 16.9 mg kg⁻¹ in plants in general. These values exceed the maximum authorised for Cu (10 mg kg⁻¹) for complete feed requirements in animal nutrition for ruminants (e.g., cattle, cows, and horses) of the

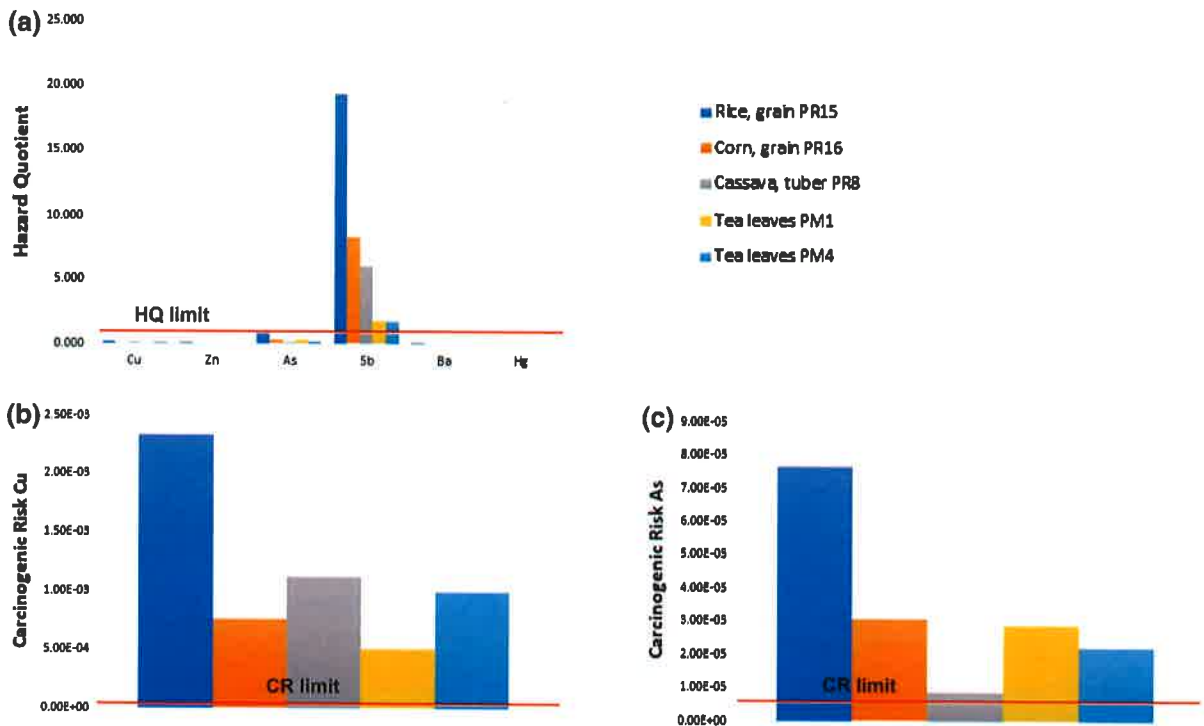


Fig. 6 **a** Bar chart for non-carcinogenic (HQ) risk for PTEs in edible plants from the Remance gold mine. **b** Carcinogenic risk for Cu in edible plants studied for the Remance gold mine. **c** Carcinogenic risk for As in edible plants studied for the Remance gold mine

National Research Council, USA (Aquilina et al., 2016; López-Alonso & Miranda, 2020; NRC, 2001). The mean Zn value in grass was 27.3 mg kg⁻¹, and 31.1 mg kg⁻¹ in plants in general. Both these values exceed the estimated value of the daily diet requirement for cattle for Zn (22.8 mg kg⁻¹) (NRC, 2001). For As, Ba, Sb, and Hg, the National Research Council of the USA does not establish an estimated value for the daily diet requirements of cattle.

Discussion

Given that the soils and plants in the surroundings of the abandoned Remance gold mine present high concentrations of PTEs, such as Cu, Zn, As, Sb, Ba, and Hg, associated with mineralisation (Nelson & Ganoza, 1999), it is essential to identify the degree to which plants, and especially the crops grown by farmers like rice, corn, cassava, among others, are affected (Ministerio de Ambiente Panamá, 2012). It is also necessary to identify the risks for livestock and as collateral risks for human health. The mean concentration of the PTEs in the leaves of a diversity of

studied plants comes in this order, Zn = Ba > Cu > Sb > As > Hg, while BAC is related to the total amount of PTEs present in soil, and the degree to which a plant absorbs them comes in this order, Zn > Sb > Cu > Hg > Ba > As. All this indicates that essential trace elements like Zn and Cu (Arif et al., 2016) are absorbed by plants and accumulate more than non-essential elements (Bravo et al., 2015) like Hg, Ba, and As.

The exception can be Sb, which being non-essential, has been strongly absorbed and accumulated by plants (Mykolenko et al., 2018), even as As, which is in larger total concentrations in soil, evidencing the availability of these PTEs, which was corroborated with the BCR extraction (where the labile or available fractures are extracted for transport and plants) (Madrid et al., 2007; Kelepertzis et al., 2013) for As and Cu, where Cu was much more available than As.

For the soil-plant transfer of PTEs, a weakly negative linear regression between the Cu concentrations in plants versus the available Cu fraction in soil (BCR) was found. Although Cu is an essential element for plants, it is toxic for them if it appears in soil in large quantities (Adrees et al., 2015; Kumar et al.,

2021; Rather et al., 2020; Shabbir et al., 2020). The relation between bioavailability indices BAC and BC (Kelepertzis et al., 2013) was positive, which reveals that plants' ability to bioaccumulate Cu is enhanced, as does its ability to bioconcentrate it when Cu is available in soil.

The scenario is different for As because the relation between the elements in plants and in soil is not as clear. Although this relation was very weakly positive, it seemed to be dominated by having low absorbed As concentrations available in soil. This is a general rule, except for *Schefflera morototoni*, which absorbs As more efficiently by having mechanisms to tolerate and accumulate this toxic element. One remarkable fact is that, although As is more available in soil, plants do not always absorb it more, mainly because it is not an essential element (Ackova, 2018) and can be more related to each plant species' capacity to exclude or tolerate this PTE (Chamba et al., 2017; Dixit et al., 2015). The relation between bioavailability indices BAC and BC was positive, which indicates that a plant's ability to bioaccumulate As increases, as does its ability to bioconcentrate As when it is available in soil.

The mean concentration of both Cu and Zn in the leaves of the plants around the Remance gold mine, compared to plants from other parts of the world, fell within the ranges known for between uncontaminated (Shtangeeva et al., 2020a, 2020b) and contaminated zones (Hussain et al., 2019), while the As, Sb and Ba values were similar to those reported from contaminated areas (Getaneh & Alemayehu, 2006; Hussain et al., 2019). More specifically, the Cu concentrations in grass were similar to those from contaminated areas (Hussain et al., 2019), while As, Sb and Ba obtained higher values than those reported in uncontaminated areas (Shtangeeva et al., 2020a, 2020b), and the Zn concentrations were similar to those from uncontaminated areas (Kabata-Pendias, 2011). All these values imply harmful effects on the health of the cattle grazing in the study area for these PTEs because they are higher than those recommended for the animal nutrition of ruminants (Johnsen & Aaneby, 2019), as is the case of Cu and Zn (NRC, 2001). However, there are no estimated requirements set for cattle according to the National Research Council, USA, for the other PTEs (As, Sb, Ba, and Hg).

The human health risk posed by eating edible plants grown in areas with PTEs can be evaluated with the

PMTDI (Gruszecka-Kosowska, 2020). This value was exceeded for Cu, Zn, Sb and Ba in all the studied edible plants (rice, corn, cassava, tea leaves), and for As in rice, corn and tea leaves, and for Hg only in tea leaves. Although some of these elements can be considered essential for plants or humans, they can be toxic to human health if consumed in excess, such as Cu, which brings about abnormalities in the nervous system, liver and kidneys, and even death, or Zn, which reduces the immune function and HDL cholesterol, and also causes fever. Non-essential PTEs can cause cirrhosis, cancer of the skin, liver and lungs, or embryo theratogenesis (As), respiratory system damage (Sb), gastroenteritis, muscle paralysis, ventricular fibrillation and extrasystoles (Ba), neurological damage (mercurialism), asthenic-vegetative syndrome or Minamata disease, kidney damage, toxicity to foetus and teratogenic embryo (Hg) (Bini & Wahsha, 2014).

The HQ values, with which the non-carcinogenic risk of edible plants is evaluated (Gruszecka-Kosowska, 2020), were exceeded for Sb, which places rice, corn, cassava, and tea leaves at risk levels. The long-term intake of small amounts of Sb may induce chronic antimony poisoning, while Sb exposure has been shown to induce DNA damage and oxidative stress, and to generate reactive oxygen species (ROS) causing apoptosis. As Sb geochemical behaviour is similar to that of As, it is likely that DNA damage induced by Sb follows similar pathways to those for As (Bini & Wahsha, 2014; Franco et al., 2009).

The acceptable CR was surpassed by all the edible plants for Cu, and also for As in rice, corn and tea leaves, which meant that the total acceptable CR was exceeded by all the studied edible plants and posed a risk for the health of the people who eat them in the studied mining area. One of the most important risks could come through As as long-term exposure can lead to skin lesions, internal cancers, neurological problems, pulmonary disease, peripheral vascular disease, hypertension and cardiovascular disease, and diabetes mellitus (Jaishankar et al., 2014; Smith et al., 2000).

The Remance gold mine is an abandoned mine. When abandoned mines are not properly shut down, they pose an environmental problem that also affects the inhabitants of their surroundings (Kaninga et al., 2020; Khlelifi et al., 2020). Therefore, environmental surveillance programmes need to be set up to avoid harming populations.

Conclusion

The flora and crops of the Remance gold mine bioaccumulated the herein studied PTEs in this order: Zn > Sb > Cu > Hg > Ba > As. This finding indicates that this area has absorbed mostly essential elements like Zn and Cu along with Sb which is non-essential but has a very high affinity to be absorbed by plants. Of the major elements in soil, such as As and Cu, Cu was more available than As. This revealed that plants bioconcentrated Cu more than As despite As found in a larger total quantity in soil.

The BAC vs. BC relation was positive for both the tested Cu and As elements, which denotes that plants' ability to bioaccumulate and bioconcentrate is linked with the availability of elements in soil.

The relationship between the Cu concentration in plants and the amount of Cu available in soil was weak and not very significant, as is the case for As. What this implies is that the amount of As available in soil was not directly linked with its concentration in plants, and this could, in turn, be linked with the mechanisms that each plant species possesses to absorb and bioaccumulate, or exclude, As.

The average Cu and Zn concentrations present in the grass and plants around the Remance gold mine exceeded the recommended requirements for the animal nutrition of ruminants according to the National Research Council, USA. So this could pose some health risks for the livestock grazing in this area.

Sb was the PTE that posed the main non CR. As and Cu were the PTEs that represented a CR because they exceeded the acceptable CR limit in the studied edible plants (rice, corn, cassava, tea leaves) that are planted and consumed by peasants as part of their daily diet.

We recommend the study area being bioremediated to reduce the posed risk for the environment and the people inhabiting the area.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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 REPÚBLICA DE PANAMÁ GOBIERNO NACIONAL		MINISTERIO DE AMBIENTE	HOJA DE TRAMITE
Fecha : 27 de abril de 2022			
Para : Despacho del Ministro		De: Secretaría General	
Pláceme atender su petición		De acuerdo ☐ URGENTE	
☐ Dar su aprobación	☐ Resolver	☐ Procede	
☐ Dar su Opinión	☐ Informarse	☐ Revisar	
☐ Discutir conmigo	☐ Encargarse	☐ Devolver	
☐ Dar Instrucciones	☐ Investigar	☐ Archivar	
Remitimos Nota sin número de los trabajadores de la comunidad de San Francisco de Veraguas, que hace referencia al Foro Público realizado por la empresa de la Mina en El Remance.			
Adjunto: lo indicado			
AGA/gd			
			

Fecha:

3/5/2022

Para:

América

De:

ING. DOMILUIS DOMÍNGUEZ E.

Pláceme atender su petición

De acuerdo

☐ URGENTE

☐ Dar su aprobación

☐ Resolver

☐ Procede

☐ Dar su Opinión

☐ Informarse

☐ Revisar

☐ Discutir conmigo

☐ Encargarse

☐ Devolver

☐ Dar Instrucciones

☐ Investigar

☐ Archivar

Nota s/n de los Trabajadores de la Comunidad
de San Francisco (Veraguas). Donde
si quieren el proyecto Minero en Romance.

03/05/2022

Se Excelentísimo:

Laurentino Cortizo C.
Presidente de la República de Panamá
E. S. D.

Lic: Milciades Concepción
Ministro de Ambiente

San Francisco y de Chiriquí 2, 022

REPÚBLICA DE PANAMÁ	MINISTERIO DE AMBIENTE
DIRECCIÓN DE EVALUACIÓN DE IMPACTO AMBIENTAL	
RECIBIDO	
Por: <i>Saunders</i>	
Fecha: <i>29/4/2022</i>	
Hora: <i>3:20 pm</i>	
<i>DOMESTIC</i>	
<i>P.S.A.</i>	
<i>M.C</i>	
<i>28/04/2022</i>	

2022 ABR 28 3:47PM

MIN. DE AMBIENTE
SECRETARIA GENERAL

Señor: Presidente:

Reciba usted un afable saludo de los trabajadores de la comunidad de San Francisco (Veraguas).

Las once (11) comunidades que participamos del Foro Público, que la empresa de la Hina Romance, hizo el día 28 de marzo en la casa Comunal de La Gorda y los de las comunidades llegamos temprano y los encargados del foro nos atendieron y tuvieron el tiempo para hablar con nosotros y decirnos que es el proyecto.

Ya no somos ignorante, como los grupos de afuera creen que somos ignorantes y sabemos cuando nos mienten y también cuando nos dicen la verdad, los que temprano hacíamos nuestras preguntas y nos respondían cada una de ella, aun sabiendo que la reunión

2022 ABR 27 10:18AM

MIN. DE AMBIENTE
SECRETARIA GENERAL

no habia comenzado, ya los de las comunidades estaban allí, con ganas de conocer mas del proyecto, porque la mina ya la conocemos, allí vivimos allí nacimos, y nuestros padres y todos nosotros crecimos allí.

No pueden venir a decirnos que lo que murio de conocer, que lo que quedó ciega y todos esas mentiras, que en esta comunidad nadie a muerto de conocer o se han quedado ciegos por culpa de la mina, para que luego personas que no viven aquí y nos quieran decir los que ellos no vivieron, por que esos grupos no son de nuestras comunidades. Pero vienen a tratarnos de ignorantes, y amonazarnos para que no digamos nada sin decirnos hablar cuando ellos viven, porque nosotros cuando comenzamos al Foro no habíamos con miedo a que ellos, a esos grupos ambientalista de maestros y de afuera que solo saben amonazar y callarnos para que solo ellos puedan hablar.

Nosotros los que vivimos aquí en esta comunidades de San Francisco, si queremos La Mina El Romance. Queremos volver a vivir el desarrollo en nuestras comunidades como lo hicieron nuestros padres, pero ahora esigundole a la empresa que cumpla con

hacer los casos bien. Ya sabemos que no son los mismos peruanos que se fueron y queremos que nos tomen en cuenta por que los gobiernos anteriores no nos tomaron en cuenta y por eso nuestros niños tienen que ir descalzos a la escuela por que no tienen zapatos, o por que si los tienen se les daña con las piedras, la polvarada y el lodazal en el camino.

Los que abajo firmamos esta nota que somos moradores y residentes del distrito de San Francisco y especialmente de las comunidades de:

La Gorda, San Juan, Los Hornos, La Hina, Naranjal, La Utria, La Honda, Los Pintos, El Ramonito, La Cruz. Hemos visto como el 28 de marzo, grupos de apura que no conocen nuestra necesidad y nuestras ganas de salir adelante, vienen en forma agresiva a muleros en la cabeza que todo proyecto que se quiera hacer en nuestra comunidad es mala doctrina que nos quieren quitar las tierras, entre cosas mas que ya sabemos que son puras mentiras, y muchas veces esta personas u organizaciones solo se acuerdan de nosotros cuando necesitan curar calles y que quitamos cosas que ellos no se atreven a decir a los gobiernos.

No queremos ser mas usados de esa forma.

Señor Presidente y señor Ministro, nosotros que si somos de la Comunidad.

Si Queremos La Mina El Remance
Saludos

Gracias

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