Supplementary material

Risk assessment of mining environmental liabilities for their categorization and prioritization in gold mining areas of Ecuador

Bryan Salgado-Almeida[1], Daniel Falquéz-Torres[1], Paola Romero-Crespo[1], Priscila Valverde-Armas[1], Fredy Guzmán-Martínez[2], and Samantha Jiménez-Oyola[1,*]

[1] Escuela Superior Politécnica del Litoral, ESPOL, Facultad de Ingeniería en Ciencias de la Tierra, Campus Gustavo Galindo km 30.5 vía Perimetral, P.O. Box 09-01-5863, Guayaquil, Ecuador.

[2] Mexican Geological Survey, Boulevard Felipe Angeles Km. 93.50-4, 42083, Pachuca, Mexico

***Corresponding author:** Samantha Jiménez-Oyola, sjimenez@espol.edu.ec

Supplementary material caption:

Table S1: Maximum and minimum concentrations of heavy metals in water, soil, and sediment samples from each study area.

Table S2: Assessment criteria of parameters for probability index determination of scenario S1 and S2

Table S3: Assessment criteria to the severity index (I_S) of scenario S1

Table S4: Assessment criteria of parameters for severity index determination of scenario S3 and S4

Table S5: Risk assessment results: scenarios S1 and S2

Table S6: Risk assessment results: scenarios S3 and S4

Table S1: Maximum and minimum concentrations of heavy metal(loid)s in water, soil, and sediment samples from each study area.

Surface water (mg/L)		**As**	**Cd**	**Cu**	**Hg**	**Pb**	**Zn**
Macuchi	(min – max)[a]	0.001 – 85	0.0001 – 4.90	0.01 – 1,103	-	0.001 – 1.10	0.01 – 364
Tenguel – Ponce	(max)[b]	0.26	0.0001	0.01	-	0.002	-
Enríquez	(max)[c]	0.47	0.01	7.28	0.001	-	0.82
	(max)[d]	0.02	0.0001	0.21	0.00002	0.0001	0.01
Puyango River	(min – max)[b]	0.002 – 0.01	0.001 – 0.002	0.01 – 0.02	-	0.001 – 0.003	-
Basin	(max)[c]	-	0.04	0.44	0.0001	-	3.35
	(max)[d]	0.06	0.001	1.43	0.001	0.01	0.11
	LMP[f]	0.05	0.001	0.02	0.0002	0.01	0.18
Soils and Sediments (mg/kg)		**As**	**Cd**	**Cu**	**Hg**	**Pb**	**Zn**
Macuchi	(min – max)[a]	17 – 325	0.20 – 5.20	69 – 1,467	-	75 – 791	33 – 562
Tenguel – Ponce	(min – max)[b]	2,070 – 7,700	1.80 – 6.05	2,420 – 2,500	0.50 – 2.00	21.80 – 70.60	-
Enríquez	(max)[c]	46,049	24	9,134	13	666	924
	(max)[d]	3,968	2.20	1,425	1.40	35.40	175
	(min – max)[e]	44 – 9,890	-	56 – 5,638	-	-	-
Puyango River	(min – max)[b]	35 – 403	3.60 – 19.60	97.60 – 1,680	0.02 – 0.10	107 – 1,310	-
Basin	(max)[c]	7,493	104	8,750	3	10,524	9,792
	(max)[d]	1,313	72.90	2,993	2.50	6,646	9,304
	LMP[f]	5	0.50	30	0.10	25	60

min: minimum values; max: maximum values; LMP: maximum allowed limit by Ecuadorian legislation.

[a] MAE-PRAS [1]; [b] Tarras-Wahlberg et al. [2] – maximum values correspond to representative concentrations during dry season; [c] Appleton et al. [3]; [d] Carling et al. [4]; [e] Sierra et al. [5] and [f] TULSMA [6].

Table S2: Assessment criteria of parameters for probability index determination of scenario S1 and S2

Scenario S1 and S2			
Scenario	**Parameter**	**Criteria**	**Value**
S1	Proximity factor to water bodies (P_R)	D ≤ 50 m	$\mathbf{P_R}$ = 1.0
		50 < D < 500 m	$\mathbf{P_R}$ = -0.0022 × D + 1.1
		D ≥ 500 m	$\mathbf{P_R}$ = 0.0
S2	Proximity factor to residential areas (P_{RR})	D ≤ 250 m	$\mathbf{P_{RR}}$ = 1.0
		250 < D ≤ 500 m	$\mathbf{P_{RR}}$ = 0.8
		500 < D ≤ 1000 m	$\mathbf{P_{RR}}$ = 0.6
		1,000 < D ≤ 2000 m	$\mathbf{P_{RR}}$ = 0.4
		2,000 < D ≤ 5000 m	$\mathbf{P_{RR}}$ = 0.2
		D > 5000 m	$\mathbf{P_{RR}}$ = 0.0
	Accessibility factor (F_{ACC})	Facilitated accessibility	$\mathbf{F_{ACC}}$ = 1
		Easily accessible	$\mathbf{F_{ACC}}$ = 0.75
		Moderately accessible	$\mathbf{F_{ACC}}$ = 0.5
		Hardly accessible	$\mathbf{F_{ACC}}$ = 0.25
		Not accessible	$\mathbf{F_{ACC}}$ = 0

D = Distance from MEL to water bodies (criteria for P_R) and residential areas (criteria for P_{RR})

Table S3: Assessment criteria to the severity index (I_S) of scenario S1

Scenario S1			
Exposure factor for surface waters (F_{SUP})*			
Distance (D)		**Value**	
D ≤ 100 m		1	
100 < D ≤ 5000 m		(-0.0002 × D +1)	
D > 5000 m		0	
Vulnerability factor of the exposed population (V_P)		**Ecological vulnerability factor (V_E)**	
Criteria	**Values**	**Criteria**	**Values**
Use of Very Highly Vulnerable Water: Supply water to the population (wells for private use and catchments of water intended for human consumption, which supply more than 50 people or population centers).	5	**Very Highly Vulnerable Resources and Ecosystems:** Sensitive areas (environmental protection of resources and ecosystems). Surface water bodies with very ecological status.	5
Highly Vulnerable Water Use: Irrigation (orchards, other crops, and pastures) and other agro-livestock uses (water troughs). Aquaculture, fishing grounds and recreational use (bathing area).	4	**Highly Vulnerable Resources and Ecosystems:** Well conserved wetlands not included in the Ramsar Convention or the INHZ. Surface water bodies with a good ecological status.	4
Use of Vulnerable Water: Recreational use (sport fishing). Water for park irrigation, etc.	3	**Vulnerable Resources and Ecosystems:** Surface water bodies with moderate ecological status.	3
Use of Low Vulnerable Water: Industrial use, generation of energy (for cooling) and other industrial uses, water for irrigation of golf courses, navigation and water transport, etc. Water: Recreational use (sport fishing). Water for park irrigation, etc.	2	**Low Vulnerable Resources and Ecosystems:** Surface water bodies with poor water status.	2
Use of Water Very Little Vulnerable: Other uses with low exposure.	1	**Very Low Vulnerable Resources and Ecosystems**: Surface water bodies with a bad ecological status.	1

* $F_{SUP\text{-}PO}$ for population and $F_{SUP\text{-}NA}$ for environment

Table S4: Assessment criteria of parameters for severity index determination of scenario S3 and S4

Scenario S3 and S4					
Amount of substance released into the Environment I		**Dangerousness (P)**		**Spread I**	
Criteria	**Values**	**Criteria**	**Values**	**Criteria**	**Values**
Very High: Greater than 500 tons	4	**Very dangerous:** Highly flammable/Very toxic/Causes immediate irreversible effects	4	**Very extensive:** Radius greater than 1 km	4
High: Between 50 and 500 tons	3	**Dangerous:** Explosive/Flammable/Corrosive	3	**Extensive:** Radius up to 1 km	3
Low: Between 5 and 49 tons	2	**Slightly dangerous:** Combustible	2	**Little extensive:** Radius less than 0.5 km (located area)	2
Very low: Less than 5 tons	1	**Not dangerous:** Slight and reversible damage	1	**Specific area:** Affected area (delimited area)	1

Affected population (V_{PO})		**Environmental quality (V_{NA})**	
Criteria	**Values**	**Criteria**	**Values**
Very high: More than 100 people	4	**Very high:** Very high damage – indiscriminate exploitation of natural resources, and there is a high level of pollution	4
High: Between 50 and 100 people	3	**High:** High damage – high level of exploitation of natural resources, and there is a moderate level of pollution	3
Low: Between 5 and 50 people	2	**Medium:** Moderate damage – moderate level of exploitation of natural resources, and there is a level of slight pollution	2
Very low: Less than 5 people	1	**Low:** Minor damage: conservation of natural resources, and there is no contamination	1

Severity Index (I_S)		
Criteria	**Impact classification**	**I_S value**
$18 \leq G_{PO/NA} \leq 20$	Critical	5
$15 \leq G_{PO/NA}$ 17	Serious	4
$11 \leq G_{PO/NA} \leq 14$	Moderate	3
$8 \leq G_{PO/NA} \leq 10$	Slight	2
$5 \leq G_{PO/NA} \leq 7$	Not relevant	1

$G_{PO/NA}$ = impact classification for the population (G_{PO}) and environment (G_{NA})

Table S5: Risk assessment results: scenarios S1 and S2

Study area	Id code	East	North	I_F(S1)	I_S(S1PO)	I_S(S1NA)	R_I(S1PO)	R_I(S1NA)	I_F(S2)	I_S(S2)	R_I(S2)
Macuchi	MA-TD-01	716858	9897463	2	5	3	10	6	3	3	9
	MA-TD-02	716745	9897662	2	5	3	10	6	2	3	6
	MA-TD-03	716760	9897533	2	5	3	10	6	3	3	9
	MA-TD-04	716737	9897537	2	5	3	10	6	3	3	9
	MA-TD-05	716579	9897721	2	5	3	10	6	2	3	6
	MA-LF-01	716048	9895083	0	4	1	0	0	0	3	0
	MA-LF-02	716132	9896407	0	5	2	0	0	2	3	6
	MA-LF-03	716467	9899336	3	5	3	15	9	3	3	9
	MA-LF-04	716502	9897876	2	5	3	10	6	2	3	6
Tenguel – Ponce Enríquez	TPE-LF-01	643678	9661435	3	4	3	12	9	1	3	3
	TPE-LF-02	643709	9661535	3	4	3	12	9	1	3	3
	TPE-LF-03	643560	9661196	0	4	3	0	0	1	3	3
	TPE-LF-04	646522	9668118	3	3	3	9	9	0	3	0
	TPE-LF-05	645353	9667555	2	4	3	8	6	1	3	3
	TPE-LF-06	641224	9662125	0	4	3	0	0	1	3	3
	TPE-LF-07	641445	9662122	2	4	3	8	6	2	3	6
	TPE-LF-08	641307	9662547	2	4	3	8	6	1	3	3
	TPE-LF-09	641489	9662514	2	4	3	8	6	2	3	6
	TPE-LF-10	641593	9662649	2	4	3	8	6	1	3	3
	TPE-LF-11	641335	9662225	3	4	3	12	9	2	3	6
	TPE-LF-12	650453	9664176	2	4	3	8	6	2	3	6
	TPE-LF-13	650277	9663678	2	4	3	8	6	2	3	6
	TPE-LF-14	649734	9663618	2	4	3	8	6	2	3	6
	TPE-LF-15	649810	9663475	2	4	3	8	6	2	3	6
	TPE-LF-16	650031	9663562	2	4	3	8	6	2	3	6
	TPE-LF-17	655420	9657012	3	3	3	9	9	1	3	3
	TPE-LF-18	657404	9659215	1	3	3	3	3	0	3	0
	TPE-LF-19	641239	9663357	1	4	3	4	3	2	3	6
	TPE-LF-20	642273	9663481	1	4	3	4	3	2	3	6
	TPE-LF-21	642325	9663468	1	4	3	4	3	2	3	6
	TPE-LF-22	642732	9663722	2	4	3	8	6	1	3	3
	TPE-LF-23	642724	9663776	3	4	3	12	9	1	3	3
	TPE-LF-24	642807	9663837	2	4	3	8	6	1	3	3
	TPE-LF-25	642874	9663722	2	4	3	8	6	1	3	3
	TPE-LF-26	643068	9663707	2	4	3	8	6	1	3	3
	TPE-LF-27	643198	9663649	3	4	3	12	9	1	3	3
	TPE-LF-28	647877	9660680	2	4	3	8	6	1	3	3
	TPE-LF-29	647716	9660577	2	4	3	8	6	1	3	3
	TPE-LF-30	642982	9664015	3	4	3	12	9	1	3	3
	TPE-LF-31	642891	9663993	3	4	3	12	9	1	3	3
	TPE-LF-32	642960	9663712	2	4	3	8	6	1	3	3
	TPE-LF-33	642882	9663916	2	4	3	8	6	1	3	3
	TPE-LF-34	644583	9660613	0	4	3	0	0	2	3	6
Puyango	PU-TD-01	651046	9596539	1	4	3	4	3	2	3	6
	PU-TD-02	650256	9597080	1	4	3	4	3	2	3	6
	PU-TD-03	651372	9594347	2	4	3	8	6	2	3	6
	PU-TD-04	650368	9596742	1	4	3	4	3	2	3	6
	PU-TD-05	650972	9593650	3	4	3	12	9	2	3	6
	PU-TD-06	651081	9593996	2	4	3	8	6	2	3	6
	PU-TD-07	649539	9597384	2	4	3	8	6	2	3	6
	PU-TD-08	651016	9586805	2	4	3	8	6	2	3	6
	PU-TD-09	652160	9588026	2	4	3	8	6	2	3	6
	PU-TD-10	651457	9587486	3	4	3	12	9	2	3	6
	PU-TD-11	650914	9586435	2	4	3	8	6	2	3	6
	PU-TD-12	650413	9595556	2	4	3	8	6	2	3	6

MA = Macuchi; TPE = Tenguel – Ponce Enriquez; PU = Puyango; LF = Landfill; TD = Tailing Deposit

Table S6: Risk assessment results: scenarios S3 and S4

Study area	ID	East	North	I_P(S3)	I_S(S3PO)	I_S(S3NA)	R_I(S3PO)	R_I(S3NA)	I_P(S4)	I_S(S4PO)	I_S(S4NA)	R_I(S4PO)	R_I(S4NA)
Macuchi	MA-ME-01	714237	9892641	3	3	2	9	6	3	2	2	6	6
	MA-ME-02	716139	9896402	3	5	5	15	15	3	4	4	12	12
	MA-ME-03	716362	9897155	3	3	2	9	6	3	2	2	6	6
	MA-ME-04	716478	9897193	3	5	5	15	15	3	4	4	12	12
	MA-ME-05	716476	9897187	3	3	2	9	6	3	2	2	6	6
Tenguel - Ponce Enriquez	TPE-ME-01	643853	9661616	3	3	2	9	6	3	2	1	6	3
	TPE-ME-02	643844	9661626	3	3	2	9	6	3	2	1	6	3
	TPE-ME-03	643714	9661529	3	3	2	9	6	3	2	1	6	3
	TPE-ME-04	643571	9661168	3	3	2	9	6	3	2	1	6	3
	TPE-ME-05	649578	9666117	3	3	2	9	6	3	2	1	6	3
	TPE-ME-06	646527	9668099	3	3	2	9	6	3	2	1	6	3
	TPE-ME-07	646515	9668106	3	3	2	9	6	3	2	1	6	3
	TPE-ME-08	646533	9668070	3	3	2	9	6	3	2	1	6	3
	TPE-ME-09	645395	9667485	3	3	2	9	6	3	2	1	6	3
	TPE-ME-10	646341	9668247	3	5	5	15	15	3	4	4	12	12
	TPE-ME-11	641501	9662347	3	3	2	9	6	3	2	1	6	3
	TPE-ME-12	641510	9662344	3	3	2	9	6	3	2	1	6	3
	TPE-ME-13	641621	9662414	3	3	2	9	6	3	2	1	6	3
	TPE-ME-14	641671	9662359	3	3	2	9	6	3	2	1	6	3
	TPE-ME-15	641715	9662389	3	3	2	9	6	3	2	1	6	3
	TPE-ME-16	641617	9662347	3	3	2	9	6	3	2	1	6	3
	TPE-ME-17	640453	9661761	3	3	2	9	6	3	2	1	6	3
	TPE-ME-18	640439	9661783	3	3	2	9	6	3	2	1	6	3
	TPE-ME-19	640417	9661782	3	3	2	9	6	3	2	1	6	3
	TPE-ME-20	641430	9662626	3	3	2	9	6	3	2	1	6	3
	TPE-ME-21	641311	9662563	3	3	2	9	6	3	2	1	6	3
	TPE-ME-22	641561	9662506	3	3	2	9	6	3	2	1	6	3
	TPE-ME-23	641553	9662442	3	3	2	9	6	3	2	1	6	3
	TPE-ME-24	641296	9662587	3	3	2	9	6	3	2	1	6	3
	TPE-ME-25	641333	9662194	3	3	2	9	6	3	2	1	6	3
	TPE-ME-26	653013	9663434	3	3	2	9	6	3	2	1	6	3
	TPE-ME-27	653148	9663515	3	3	2	9	6	3	2	1	6	3
	TPE-ME-28	648472	9666352	3	3	2	9	6	3	2	1	6	3
	TPE-ME-29	649031	9666848	3	3	2	9	6	3	2	1	6	3
	TPE-ME-30	651593	9662493	3	5	5	15	15	3	4	4	12	12
	TPE-ME-31	651482	9662444	3	5	5	15	15	3	4	4	12	12
	TPE-ME-32	651452	9662452	3	3	2	9	6	3	2	1	6	3
	TPE-ME-33	651412	9662420	3	5	5	15	15	3	4	4	12	12
	TPE-ME-34	651341	9662353	3	3	2	9	6	3	2	1	6	3
	TPE-ME-35	651333	9662327	3	3	2	9	6	3	2	1	6	3
	TPE-ME-36	651311	9662268	3	3	2	9	6	3	2	1	6	3
	TPE-ME-37	649806	9663466	3	3	2	9	6	3	2	1	6	3
	TPE-ME-38	650032	9663530	3	3	2	9	6	3	2	1	6	3
	TPE-ME-39	648768	9665014	3	3	2	9	6	3	2	1	6	3
	TPE-ME-40	648882	9665063	3	5	5	15	15	3	4	4	12	12
	TPE-ME-41	648962	9664784	3	5	5	15	15	3	4	4	12	12
	TPE-ME-42	649717	9663608	3	3	2	9	6	3	2	1	6	3
	TPE-ME-43	649732	9663577	3	5	5	15	15	3	4	4	12	12
	TPE-ME-44	649759	9663583	3	5	5	15	15	3	4	4	12	12
	TPE-ME-45	650024	9663525	3	5	5	15	15	3	4	4	12	12
	TPE-ME-46	650027	9663547	3	3	2	9	6	3	2	1	6	3
	TPE-ME-47	655993	9657437	3	3	2	9	6	3	2	1	6	3
	TPE-ME-48	655421	9657015	3	3	2	9	6	3	2	1	6	3
	TPE-ME-49	642703	9663716	3	3	2	9	6	3	2	1	6	3
	TPE-ME-50	642817	9663824	3	5	5	15	15	3	4	4	12	12
	TPE-ME-51	642886	9663709	3	5	5	15	15	3	4	4	12	12
	TPE-ME-52	643070	9663699	3	5	5	15	15	3	4	4	12	12

	TPE-ME-53	643192	9663638	3	3	2	9	6	3	2	1	6	3
	TPE-ME-54	641252	9663342	3	5	5	15	15	3	4	4	12	12
	TPE-ME-55	643069	9663702	3	3	2	9	6	3	2	1	6	3
	TPE-ME-56	647886	9660643	3	3	2	9	6	3	2	1	6	3
	TPE-ME-57	647681	9660548	3	3	2	9	6	3	2	1	6	3
	TPE-ME-58	647699	9660557	3	5	5	15	15	3	4	4	12	12
	TPE-ME-59	642973	9663988	3	3	2	9	6	3	2	1	6	3
	TPE-ME-60	642959	9663694	3	3	2	9	6	3	2	1	6	3
	TPE-ME-61	642877	9663891	3	3	2	9	6	3	2	1	6	3
	TPE-ME-62	642940	9664029	3	3	2	9	6	3	2	1	6	3
	TPE-ME-63	642918	9663973	3	3	2	9	6	3	2	1	6	3
	TPE-ME-64	642948	9663702	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-01	650450	9664243	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-02	650588	9664124	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-03	650447	9664162	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-04	650308	9663673	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-05	649723	9663579	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-06	657406	9659216	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-07	641264	9663325	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-08	642309	9663464	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-09	641634	9663871	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-10	642757	9663697	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-11	641649	9663874	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-12	641665	9663904	3	3	2	9	6	3	2	1	6	3
	TPE-ABI-13	642737	9663724	3	3	2	9	6	3	2	1	6	3
Puyango	PU-MG-01	654237	9592641	3	5	5	15	15	3	4	4	12	12
	PU-MG-02	654252	9592554	3	5	5	15	15	3	4	4	12	12
	PU-MG-03	654237	9592641	3	5	5	15	15	3	4	4	12	12
	PU-MG-04	654418	9593831	3	5	5	15	15	3	4	4	12	12
	PU-MG-05	694557	9593532	3	5	5	15	15	3	4	4	12	12
	PU-MG-06	655181	9597272	3	5	5	15	15	3	4	4	12	12
	PU-MG-07	651929	9596624	3	5	5	15	15	3	4	4	12	12
	PU-MG-08	651744	9598569	3	5	5	15	15	3	4	4	12	12
	PU-MG-09	648266	9599340	3	5	5	15	15	3	4	4	12	12
	PU-MG-10	633281	9591926	3	5	5	15	15	3	4	4	12	12
	PU-MG-11	653325	9591957	3	5	5	15	15	3	4	4	12	12
	PU-MG-12	655137	9587755	3	5	5	15	15	3	4	4	12	12
	PU-MG-13	654303	9588317	3	5	5	15	15	3	4	4	12	12
	PU-MG-14	655369	9587736	3	5	5	15	15	3	4	4	12	12
	PU-MPP-01	653851	9596547	3	5	5	15	15	3	4	4	12	12
	PU-MPP-02	653712	9596356	3	5	5	15	15	3	4	4	12	12
	PU-MPP-03	652424	9603129	3	5	5	15	15	3	4	4	12	12
	PU-MPP-04	648463	9604985	3	5	5	15	15	3	4	4	12	12
	PU-MPP-05	655648	9594476	3	5	5	15	15	3	4	4	12	12
	PU-MPP-06	655677	9594316	3	5	5	15	15	3	4	4	12	12
	PU-MPP-07	657092	9594960	3	5	5	15	15	3	4	4	12	12
	PU-MPP-08	656309	9592941	3	5	5	15	15	3	4	4	12	12
	PU-MPP-09	655005	9592610	3	5	5	15	15	3	4	4	12	12
	PU-MPP-10	650948	9586396	3	5	5	15	15	3	4	4	12	12
	PU-MPP-11	654362	9588079	3	5	5	15	15	3	4	4	12	12
	PU-AT-01	651680	9588167	3	5	5	15	15	3	4	4	12	12
	PU-AT-02	650462	9584615	3	5	5	15	15	3	4	4	12	12
	PU-AT-03	618539	9576745	3	5	5	15	15	3	4	4	12	12
	PU-QR-01	646914	9606952	3	5	5	15	15	3	4	4	12	12
	PU-QR-02	621749	9579910	3	5	5	15	15	3	4	4	12	12

MA = Macuchi; TPE = Tenguel – Ponce Enriquez; PU = Puyango; ME = Mine entrance; ABI = Abandoned infrastructure; MG = Mining gallery (Mine); MPP = Mineral processing plant; AT = Alluvial terrace; QR = Quarry

References

1. MAE-PRAS *Programa de Reparación Ambiental Y Social - Plan de Reparación Integral Macuchi*; 2015; Vol. I;

2. Tarras-Wahlberg, N.H.; Flachier, A.; Fredriksson, G.; Lane, S.; Lundberg, B.; Sangfors, O. Environmental Impact of Small-Scale and Artisanal Gold Mining in Southern Ecuador. *Ambio* **2000**, *29*, 484–491, doi:10.1579/0044-7447-29.8.484.

3. Appleton, J.D.; Williams, T.M.; Orbea, H.; Carrasco, M. Fluvial Contamination Associated with Artisanal Gold Mining in the Ponce Enríquez, Portovelo-Zaruma and Nambija Areas, Ecuador. *Water, Air, and Soil Pollution* **2001**, *131*, 19–39, doi:10.1023/A:1011965430757.

4. Carling, G.T.; Diaz, X.; Ponce, M.; Perez, L.; Nasimba, L.; Pazmino, E.; Rudd, A.; Merugu, S.; Fernandez, D.P.; Gale, B.K.; et al. Particulate and Dissolved Trace Element Concentrations in Three Southern Ecuador Rivers Impacted by Artisanal Gold Mining. *Water, Air, and Soil Pollution* **2013**, *224*, doi:10.1007/s11270-012-1415-y.

5. Sierra, C.; Ruíz-Barzola, O.; Menéndez, M.; Demey, J.R.; Vicente-Villardón, J.L. Geochemical Interactions Study in Surface River Sediments at an Artisanal Mining Area by Means of Canonical (MANOVA)-Biplot. *Journal of Geochemical Exploration* **2017**, *175*, 72–81, doi:10.1016/j.gexplo.2017.01.002.

6. TULSMA *Texto Unificado de Legislación Secundaria de Medio Ambiente Norma De Calidad Ambiental Del Recurso Suelo Y Criterios De Remediación Para Suelos Contaminados*; 2015;