

SUPPLEMENTARY MATERIAL

for the paper

Incorporating remote sensing techniques to the DRASTIC index to assess groundwater vulnerability at mining areas: application to Sonora river aquifer, northwestern Mexico

by

**Denisse Archundia, Víctor Vidaña-Guillen, Juan Valenzuela-Munguia,
and Francisco Molina-Freaner**

Publicado en Revista Mexicana de Ciencias Geológicas, v. 39, núm. 3, 2022, p. 248-261.

DOI: <https://doi.org/10.22201/cgeo.20072902e.2022.3.1683>

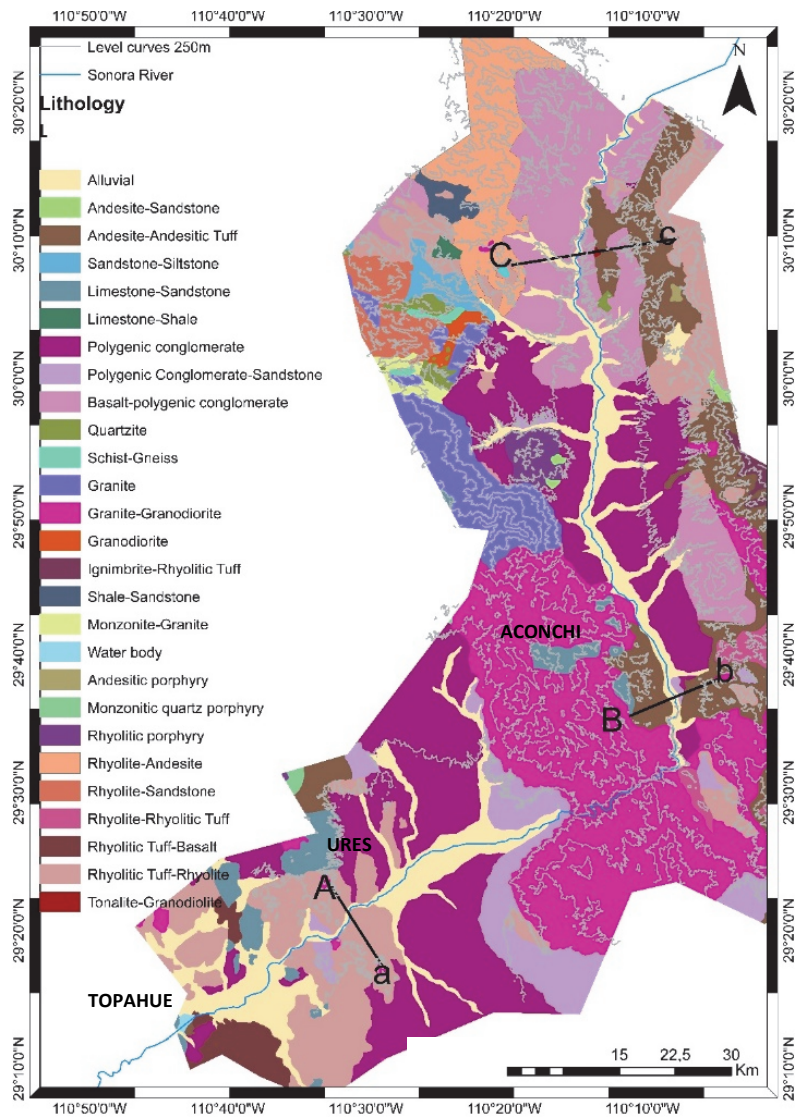


Figure SI.1. Lithology of the study area (continues).

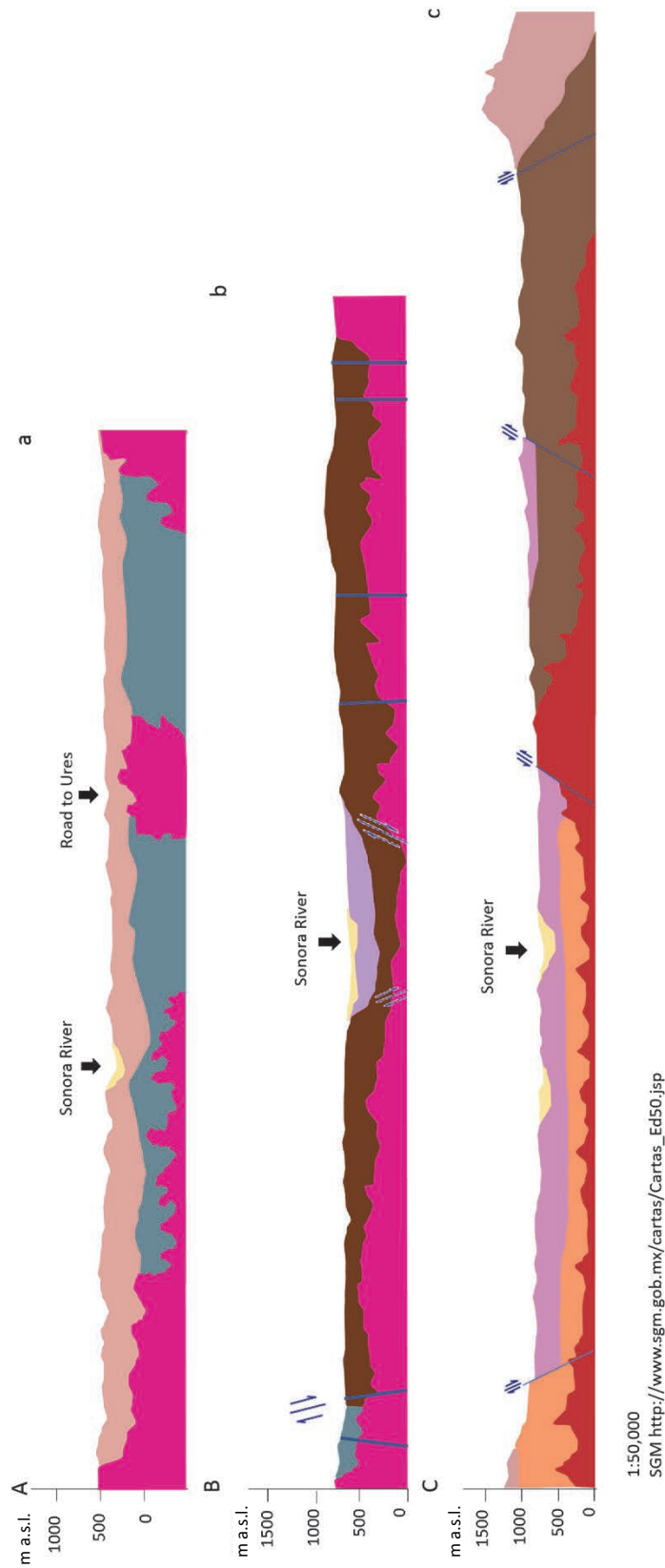


Figure SI.2. Cross sections on the study area, the lithology is represented in Figure SI.1.

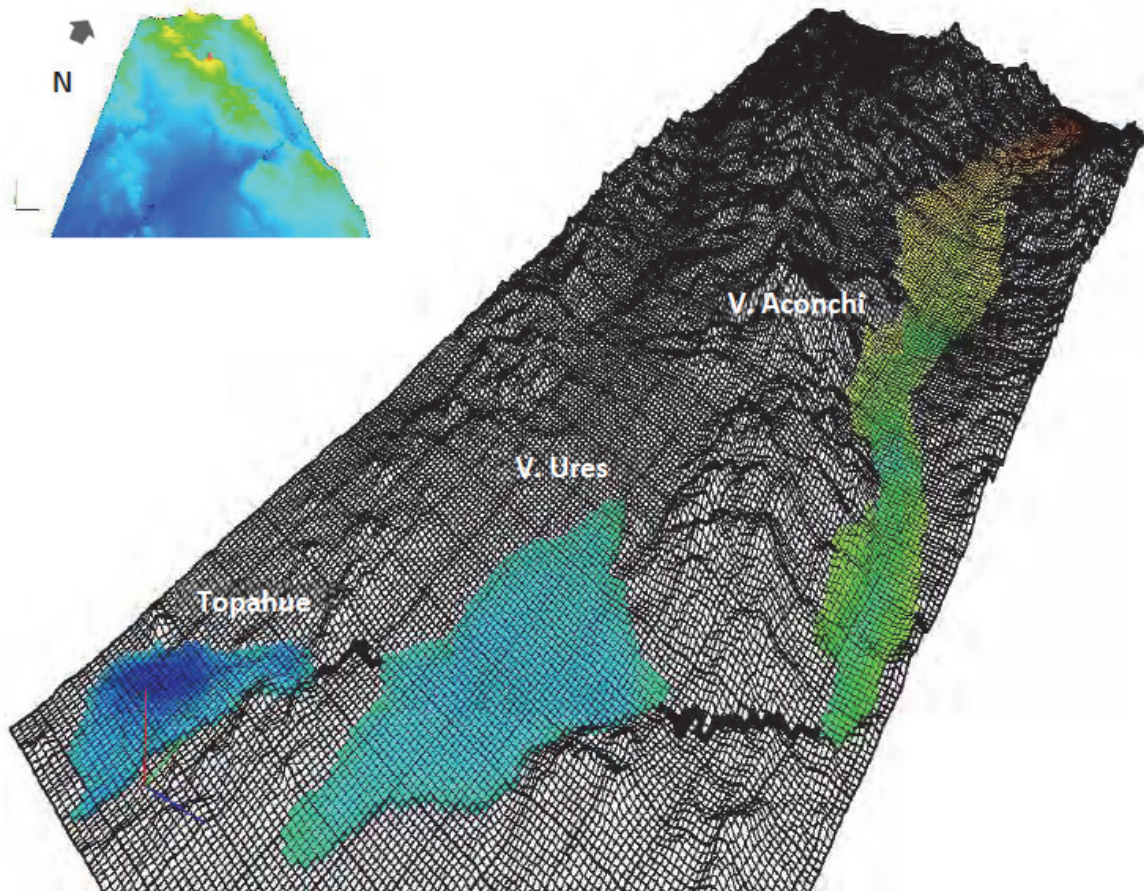


Figure SI.3. Hydrogeological units conforming the Sonora river aquifer (Fajardo Calzada, 2016).

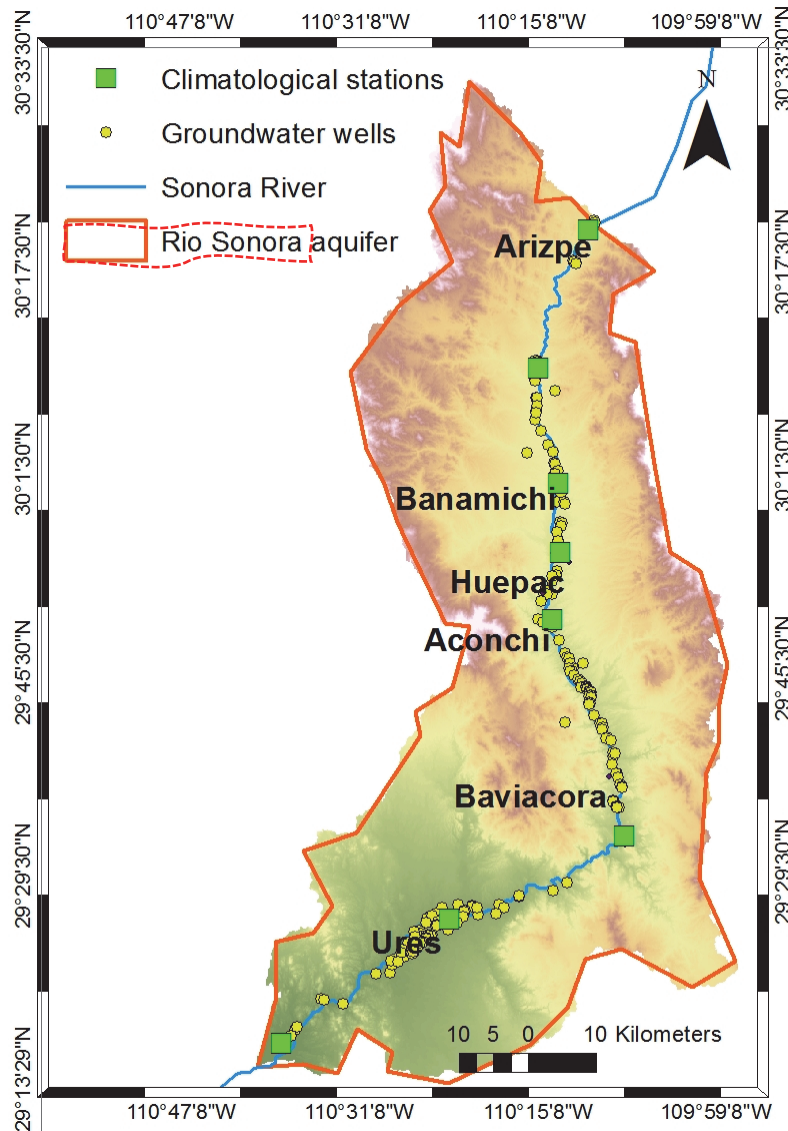


Figure SI.4. Comisión Nacional del Agua (CONAGUA) supply wells used for calculating the Depth parameter and climatological stations used to calculate the Recharge parameter.

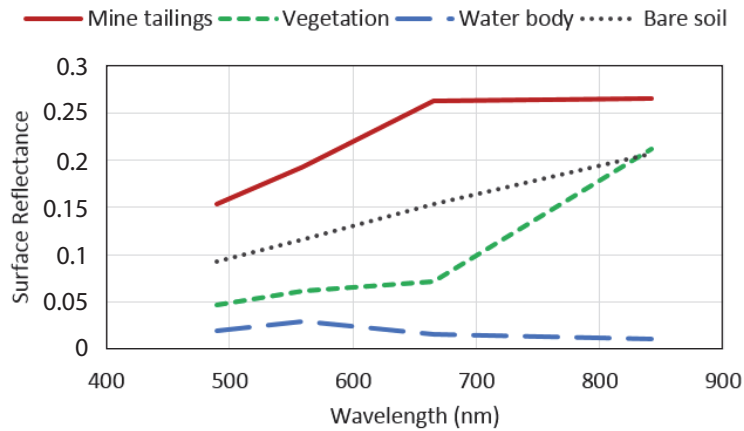


Figure SI.5. Spectral curves for representative surface features in the Sentinel 2 image.

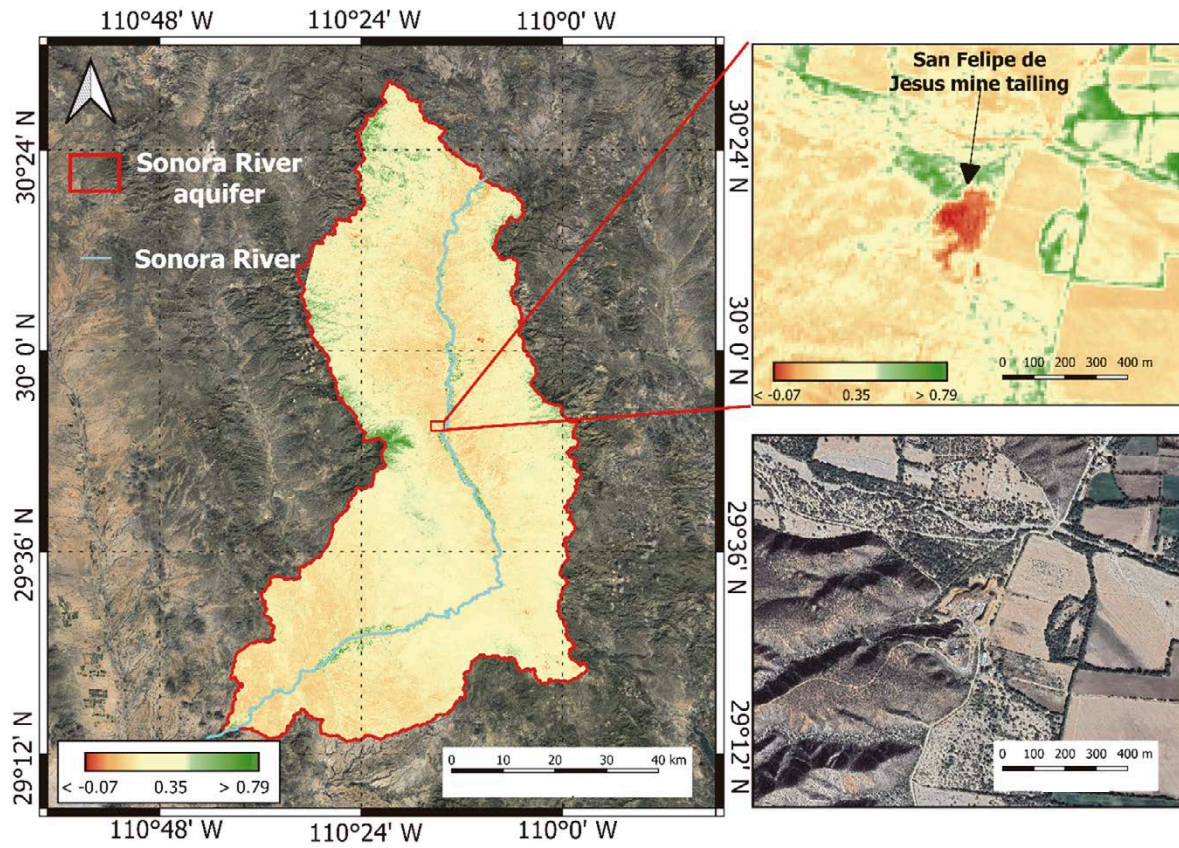


Figure SI.6. Spatial variation of NDVI. To the right we can see NDVI at the San Felipe de Jesús mine tailing and the same site without NDVI.

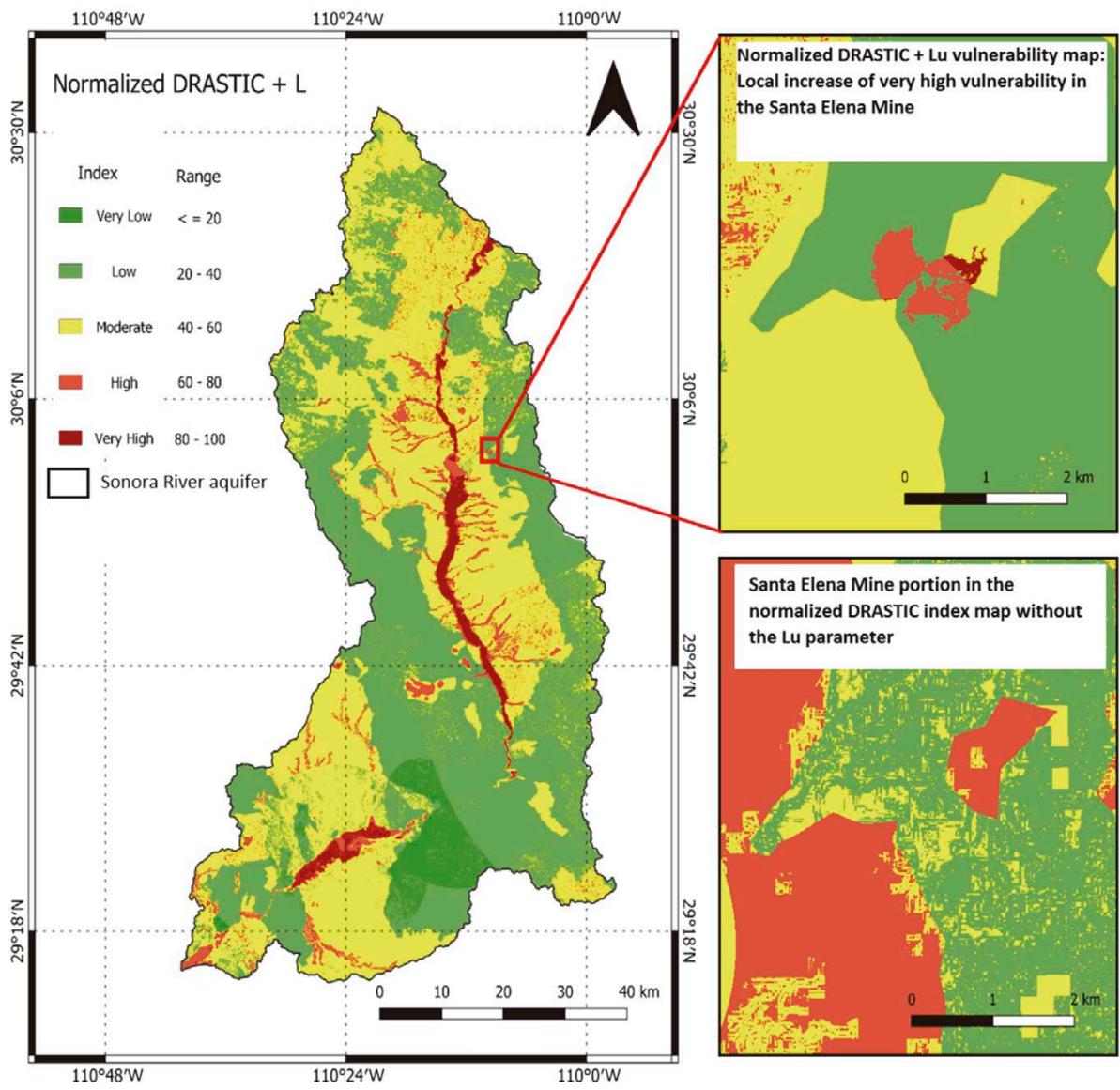


Figure SI.7. Increase of vulnerability in the vicinity of metal pollution sources in the normalized DRASTIC + Lu index map.

Table S1.1. DRASTIC rating and weighting values for the hydrogeological parameters.

| DRASTIC parameters | Range | Rating | Weight |
|------------------------------|---------------------|--------|--------|
| Depth to water table(m) | | | 5 |
| | <1 | 10 | |
| | 1–2 | 9 | |
| | 2–4 | 8 | |
| | 4–10 | 7 | |
| | >10 | 5 | |
| Net recharge | | | 4 |
| | <8 | 1 | |
| | 8–16 | 3 | |
| | 16–28 | 6 | |
| | 28–40 | 8 | |
| | >40 | 9 | |
| Aquifer media | | | 3 |
| | Sandstone | 6 | |
| | Fine sand | 8 | |
| Soil media | | | 2 |
| | Sand | 10 | |
| | Sandstone | 6 | |
| Topography (slope %) | | | 1 |
| | <2 | 10 | |
| | 2–6 | 9 | |
| | 6–12 | 5 | |
| | 12–18 | 3 | |
| | <18 | 1 | |
| Impact of the vadose zone | | | 5 |
| | Loam | 1 | |
| | Sandstone | 3 | |
| | Loess | 5 | |
| | Weathered sandstone | 6 | |
| | Sand | 9 | |
| Hydraulic conductivity (m/d) | | | 3 |
| | <0.5 | 1 | |
| | 0.5–1 | 3 | |
| | 1–1.5 | 6 | |
| | >1.5 | 10 | |

Table S1.2. Data for the calculation of the Recharge parameter. P: average precipitation (mm), L: thermal indicator ($L=300+0.25T+0.05T^3$), ET: evapotranspiration (mm).

| Climatological station | Latitude | Longitude | Date | Elevation (m a.s.l.) | Average Precipitation (mm) | Average temperature (°C) | L | P/L | ET (mm) | Net recharge (mm/yr) |
|------------------------|----------|-----------|-----------|----------------------|----------------------------|--------------------------|----------|-------|---------|----------------------|
| Arizpe | 30.336° | -110.168° | 1961–2011 | 836 | 451.40 | 19.80 | 1183.120 | 0.382 | 339.34 | 112.06 |
| Banamichi | 30.004° | -110.215° | 1961–2011 | 675 | 450.10 | 21.80 | 1363.012 | 0.330 | 351.94 | 98.16 |
| Ures (SMN) | 29.433° | -110.383° | 1921–2011 | 387 | 399.60 | 22.70 | 1452.354 | 0.275 | 399.60 | 0.00 |
| Mazocahui | 29.541° | -110.119° | 1976–2011 | 499 | 553.80 | 21.30 | 1315.680 | 0.421 | 404.35 | 149.45 |
| Huepac | 29.913° | -110.213° | 1979–2011 | 644 | 507.40 | 19.6 | 1166.477 | 0.435 | 366.71 | 140.69 |
| Sinoquipe | 30.156° | -110.245° | 1982–2011 | 836 | 544.00 | 21.10 | 1297.197 | 0.419 | 397.65 | 146.35 |
| Topahue | 29.271° | -110.636° | 1981–2011 | 300 | 456.90 | 22.80 | 1462.618 | 0.312 | 362.31 | 94.59 |
| Aconchi | 29.825° | -110.226° | 1998–2011 | 616 | 462.00 | 21.20 | 1306.406 | 0.354 | 354.75 | 107.25 |

Table SI.3. Location of the sources of metallic pollution detected by remote sensing.

| No. of metal pollution source | Name of metal pollution source | Description of metal pollution source | Coordinates (UTM zone 12N) | |
|-------------------------------|--|--|----------------------------|------------|
| | | | X | Y |
| 1 | El Gachi Mine | Abandoned mine de Ag, Zn y Pb | 585304.88 | 3351480.6 |
| 2 | El Carmen Mine tailings | Tail of El Carmen Mine | 581315.91 | 3341461.84 |
| 3 | El Carmen Mine | Abandoned mine de Ag y Au | 581280.8 | 3341508.51 |
| 4 | Exposed natural geochemical anomaly | Hematite, jarosite, quartz and pyrite near the "Cerro Colorado" Mine | 579570 | 3335190.69 |
| 5 | Exposed natural geochemical anomaly | Near the "Zatecona" mine, Abandoned Underground Au and Ag Mine | 561695.75 | 3330125.19 |
| 6 | Santa Elena Mine tailings | Mine tailings | 580432.07 | 3321547.65 |
| 7 | Santa Elena Mine | Open pit Au and Ag mine | 580924.55 | 3321339.63 |
| 8 | El Encinal Mine | Mining wastes | 588719.81 | 3313287.46 |
| 9 | Rock waste | Rock waste located 2 km from Huépac | 574160.48 | 3309905.43 |
| 10 | La Plomosa Mine | Excavation near La Plomosa mine (Abandoned) | 570836.55 | 3309092.14 |
| 11 | Excavations, removal or wastes | Excavations, removal or wastes located 1km to the west El Carrizo mine (abandoned) | 585547.01 | 3307630.47 |
| 12 | Washington Mine | Abandoned mine Cu and W | 590127.91 | 3307620.09 |
| 13 | La Bonita Mine | Abandoned mine Cu, Pb and Zn | 592664.43 | 3304390.11 |
| 14 | San Felipe Mine tailings | Mine tailings San Felipe – El Lavadero mines | 572705.57 | 3302349.16 |
| 15 | Excavations, removal or wastes | Located 600 m northwest of El Arroyo – La Mendocilla abandoned mine | 570404.26 | 3306681.37 |
| 16 | Mine tailings of La Mendocilla–San Felipe mine | Abandoned mine Zn, Pb and Cu | 569342.06 | 3307388.03 |
| 17 | Mine tailings Santa Rosa | Mine tailings of Santa Rosa mine | 568671.25 | 3306951.58 |
| 18 | Excavations, removal or wastes | Near de abandoned San Felipe mine | 568725.43 | 3305087.03 |
| 19 | Mine tailings of the San Felipe mine | Mine tailings of the abandoned San Felipe mine | 568581.21 | 3305113.86 |
| 20 | San Felipe mine | Abandoned Au, Ag, Cu, Pb and Zn mine | 568530.06 | 3305165.43 |
| 21 | La Ventana I mine | Abandoned de Pb, Zn and Cu mine | 567391.98 | 3306543.75 |
| 22 | La Ventana I mine | Excavations, removal or wastes near La Ventana I abandoned mine | 567586.52 | 3306567.64 |
| 23 | San Felipe mine | Excavations, removal or wastes near the San Felipe abandoned mine | 567522.79 | 3305745.9 |
| 24 | San Felipe mine | Excavations, removal or wastes near the San Felipe abandoned mine | 567287.16 | 3305793.69 |
| 25 | Excavations, removal or wastes | Excavations, removal or wastes located 500 m northwest of Las Lamas abandoned mine | 566938.97 | 3305278.42 |
| 26 | La Bombita mine | Excavations, removal or wastes near La Bombita abandoned mine | 596316.29 | 3303058.02 |
| 27 | Las Cabezas mine | Excavations, removal or wastes near Las Cabezas abandoned mine | 596033.92 | 3301013.29 |
| 28 | Las Cabezas mine | Excavations, removal or wastes near Las Cabezas abandoned mine | 596185.9 | 3300687.95 |
| 29 | Las Cabezas mine | Abandoned Cu, Zn and Mo mine | 595941.05 | 3300628.83 |
| 30 | Las Cabezas mine | Excavations, removal or wastes near Las Cabezas abandoned mine | 595750.08 | 3300524.75 |
| 31 | Las Cabezas mine | Excavations, removal or wastes near Las Cabezas abandoned mine | 595842.74 | 3300461.44 |
| 32 | Las Cabezas mine | Excavations, removal or wastes near Las Cabezas abandoned mine | 595889.7 | 3300322.67 |
| 33 | Excavations, removal or wastes | Excavations, removal or wastes located 2 km east to Las Cabezas abandoned mine | 597769.34 | 3300424.76 |
| 34 | Excavations, removal or wastes | Excavations, removal or wastes located 2 km east to Las Cabezas abandoned mine | 598071.21 | 3299680.15 |
| 35 | Abandoned mine | Abandoned mine Au and Ag | 578028.91 | 3287846.96 |
| 36 | El Realito | Processing plant Fe, Au and Ag | 580580.74 | 3284847.58 |
| 37 | Wastes | Located 1 km southwest of El Realito Processing plant | 579746.41 | 3284143.64 |
| 38 | Tocapuchi Mine | Au and Ag mine (in operation) | 577949.88 | 3282604.96 |
| 39 | Excavations, removal or wastes | Excavations, removal or wastes located 1.5 km south to El Alamo abandoned mine | 578394.3 | 3279043.76 |
| 40 | Excavations, removal or wastes | Excavations, removal or wastes located 2 km south to El Alamo abandoned mine | 578794.69 | 3278770.41 |
| 41 | Excavations, removal or wastes | Excavations, removal or wastes located south to El Alamo abandoned mine | 578256.57 | 3278257.23 |
| 42 | Excavations, removal or wastes | Excavations, removal or wastes located 3 km east to La Abundancia abandoned mine | 578461.17 | 3276007.07 |
| 43 | Excavations, removal or wastes | Excavations, removal or wastes located at the east to La Abundancia abandoned mine | 578471.23 | 3275864.52 |
| 44 | Excavations, removal or wastes | Excavations, removal or wastes located at the east to La Abundancia abandoned mine | 578550.89 | 3275848.58 |
| 45 | Excavations, removal or wastes | Excavations, removal or wastes located 1.8km east to La Abundancia abandoned mine | 579438.88 | 3275436.03 |

continues

Table SI.3 (cont.). Location of the sources of metallic pollution detected by remote sensing.

| No. of metal pollution source | Name of metal pollution source | Description of metal pollution source | Coordinates (UTM zone 12N) | |
|-------------------------------|-------------------------------------|---|----------------------------|------------|
| | | | X | Y |
| 46 | Excavations, removal or wastes | Excavations, removal or wastes located 3km east to La Abundancia abandoned mine | 579417.5 | 3275185.32 |
| 47 | Excavations, removal or wastes | Excavations, removal or wastes located east to La Abundancia abandoned mine | 579286.27 | 3275211.31 |
| 48 | Exposed natural geochemical anomaly | Near El Aguilillo Fe abandoned mine | 586741.97 | 3273342.04 |
| 49 | Rock pile | 5.5 km north to Mazocahui | 585219.22 | 3273202.85 |
| 50 | Rock pile | North to Mazocahui | 584961.79 | 3273321.92 |
| 51 | Rock pile | North to Mazocahui | 584503.12 | 3273379.77 |
| 52 | Peña Blanca mine | Abandoned mine Fe | 582260.92 | 3270689.8 |
| 53 | Rock pile | 2 km north to Mazocahui | 584897.65 | 3270009.34 |
| 54 | Rock pile | 1.3 km north to Mazocahui | 584974.37 | 3269166.21 |
| 55 | Excavations, removal or wastes | 1 km the Inés abandoned mine | 583074.71 | 3266146.28 |
| 56 | Mine | Prospect mining site Pb, Zn, Cu and Ag | 543682.73 | 3255273.2 |
| 57 | Excavations, removal or wastes | 8.5 km southeast Ures | 567627.92 | 3255284.1 |
| 58 | Excavations, removal or wastes | 4.7 km east Ures | 563681.84 | 3256363.7 |
| 59 | Excavations, removal or wastes | 800 m south Huépac | 575861.76 | 3308313.76 |
| 60 | Excavations, removal or wastes | South Huépac | 576453.34 | 3308173.72 |