PS Use of Geophysics, SRTM and Remote Sensing to Characterize Groundwater Contamination from Oil Shale Wastes in South China*

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Abstract

Mapping the extent of groundwater contamination beneath landfills and hazardous waste sites is a major environmental challenge, particularly in developing countries. Monitoring wells are scarce, expensive, and commonly fail to define the full extent of contamination. Remote sensing observations from Earth orbit, as well as geophysical methods operating at the Earth's surface, offer innovative and noninvasive tools for identifying subsurface contamination in these situations, as illustrated by this study of the Maoming oil shale landfills.

Between the 1950's and 1990's oil shale mining and retorting northwest of Maoming City, southern China, produced 50 million tons of waste that were dumped in two huge landfills averaging 6-7 km long, 1-2 km wide and 5-6 m high. Rainfall and surface water percolating through the waste has led to pollution of adjacent aquifers by landfill leachate containing heavy metals and organic compounds. Values of pH as low as 3.0 have been measured in some residential and village municipal wells adjacent to the landfills. Resistivity soundings and profiles were made over and adjacent to the north landfill in 2001, in conjunction with sampling water quality in village wells surrounding the landfill. Soundings identified a very low-resistivity layer (less than 10 ohm-m) at 5-6 m depth in a village with contaminated wells about 1 km southwest of the north landfill - this conductive zone may represent leachate contamination of a shallow confined aquifer. Resistivity models, combined with groundwater specific conductance values, suggest an apparent formation factor of 10.6 + 2.8 for the oil shale waste and formation factors of 1.7 - 3.9 for the Laohuling Formation aquifer that surrounds the landfill. This information, and other electrical properties of these formations, will be used to design and model

future 2D resistivity and EM surveys. In addition, Shuttle Radar Topography Mission (SRTM) data provide excellent constraints on elevation of the north landfill and may be used to infer water table elevations, based on elevation of surface water bodies. Landsat Thematic Mapper, and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data have also proven useful in defining the extent of waste areas and their degree of vegetation. Remote sensing the extent and type of vegetation will be useful in planning and monitoring phytoremediation at this site.

Acknowledgements

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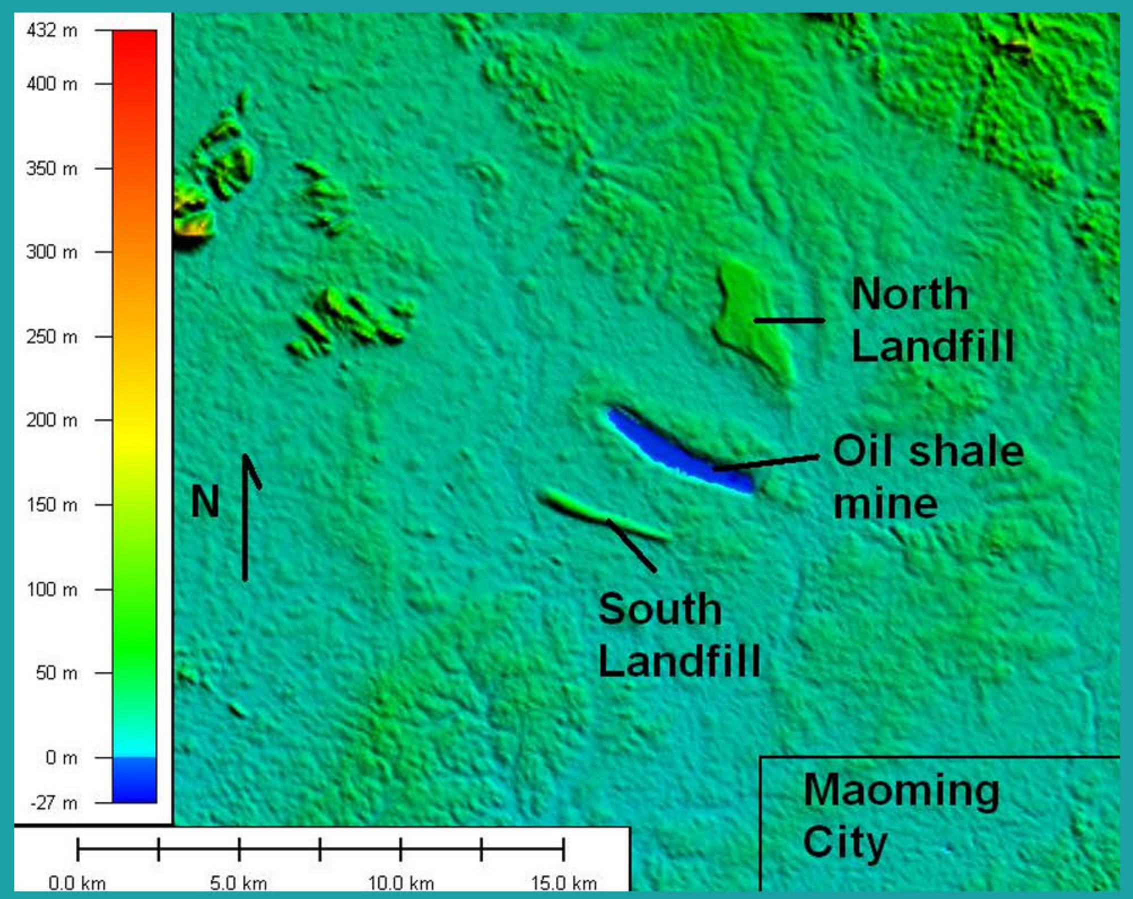
Abstract

Mapping the extent of groundwater contamination beneath landfills and hazardous waste sites is a major environmental challenge, particularly in developing countries. Monitoring wells are scarce, expensive, and commonly fail to define the full extent of contamination. Remote sensing observations from Earth orbit, as well as geophysical methods operating at the Earth's surface, offer innovative and noninvasive tools for identifying subsurface contamination in these situations, as illustrated by this study of the Maoming oil shale landfills. Between the 1950s and 1990s oil shale mining and retorting northwest of Maoming City, southern China, produced 50 million tons of waste that were dumped into two huge landfills averaging 6–7 km long, 1–2 km wide and 5–6 m high. Rainfall and surface water percolating through the waste has led to pollution of adjacent aquifers by landfill leachate containing heavy metals and organic compounds. Values of pH as low as 3.0 have been measured in some residential and village municipal wells adjacent to the landfills. Resistivity soundings and profiles were made over and adjacent to the north landfill in 2001, in conjunction with sampling water quality in village wells surrounding the landfill. Soundings identified a very low-resistivity layer (less than 10 ohm-m) at 5–6 m depth in a village with contaminated wells, about 1 km southwest of the north landfill. This conductive zone may thus represent leachate contamination of a shallow confined aquifer. Resistivity models, combined with groundwater specific conductance values, suggest an apparent formation factor of 10.6+2.8 for the oil shale waste and formation factors of 1.7– 3.9 for the Laohuling Formation aquifer that surrounds the landfill. This information and other electrical properties of these formations will be used in designing and modeling future 2D resistivity and EM surveys. Data from the Shuttle Radar Topography Mission (SRTM) provide excellent constraints on elevation of the north landfill and may be used to infer water table elevations, based on elevation of surface water bodies. Landsat Thematic Mapper, and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data have also proven useful in defining the extent of waste areas and their degree of vegetation. Remote sensing the extent and type of vegetation may be of great use for phytoremediation at this site.

Keywords: oil shale waste, leachate, landfill, groundwater contamination, geophysics, remote sensing, Maoming



SRTM image of the of the oil shale mining district north of Maoming City.

Groundwater Contamination

Acidification of groundwater

High sulfate content

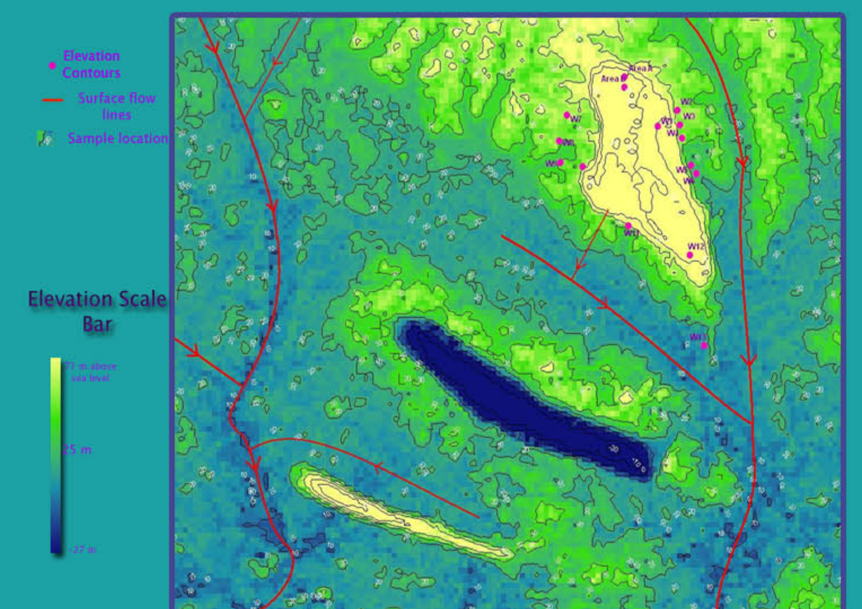
Heavy metals

Organic contaminants

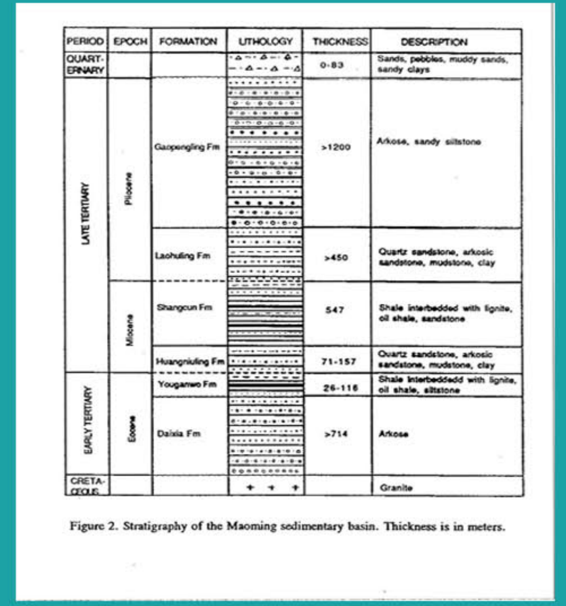
Maoming Well Data (March,2000)

	Easting	Northing	Elevation	Cond.	TDS	pH	Cl	SO4	NO3	NH3	Fe3	TOC	K	Na	Ca	Mg	Pb	Mn
W1	488189	2406565	44	1964	975	5.91	12.6	341	0.24	13.6	13	0.94	31.19	21.22	365.29	52.27	0.0073	0.00829
W2	488613	2406984	37	299	299	4.63	15.9	23	0.46	1.9	1.16	1.4	8.7	14.62	75.5	15.44	0.11	0.00979
W3	488630	2406715	33	1458	733	3.76	12.3	692	1.1	3.7	0.76	1.2	15.29	16.4	179.6	38.99	0.44	0.01336
W4	488659	2406445	37	680	343	4.28	13.2	298	1.6	1.4	0.95	1.1	10.46	13.37	79.6	15.8	0.22	0.0045
W5	488749	2406245	23	754	378	4.2	12	319	1.3	1.8	1.1	1.2	11.52	15.16	80.6	17.61	0.0497	0.00607
W6	488895	2406014	22	985	496	3.49	19	470	0.88	3	7.2	1.6	8.35	14.27	71.4	23.8	0.035	0.00714
W7	487425	2407001	35	1986	1010	2.95	18.9	724	0.96	3.8	7.4	0.29	23.28	9.63	104.1	37.39	0.0103	0.00829
W8	487031	2406198	33	132	66.7	6.7	9.4	0.2	0.68	0.05	0.6	0.2	1.75	4.65	20.8	0.3	0.0081	0.00001
W9	487356	2405809	31	148	73.3	5.18	9.1	974	0.48	0.12	1.28	0.32	1.98	4.28	6	2.44	0.0079	0.0005
W10	487726	2405551	36	474	240	4.42	34.7	975	10	0.13	1.85	1.2	10.72	18.01	32.7	7.31	0.0352	0.00084
W11	488538	2405038	30	2740	1370	3.05	16.4	195	0.76	1.1	10.6	0.66	48.95	16.76	205.1	77.22	0.0038	0.01386
W12	489240	2404204	52	294	148	7.1	17	96	1.4	0.85	0.79	0.99	8.8	16.05	35.7	5.87	0.0064	0.00029
W13	489661	2403069	16	555	279	5.87	29.6	170	1.1	0.15	0.6	0.8	9.75	21.4	77.6	8.92	0.0056	0.00044

SRTM contour map of field site generated with Global Mapper™ and ArcGIS™



Map generated using SRTM data and ArcGIS. Surface flow lines interpolated from elevation contours.



Tertiary and Quaternary stratigraphy of the Maoming basin (after Yuan and Murray, 1993)

Objectives

Map the water table across the north landfill

Assess the potential for pollution of deeper confined aquifers

Timeline and Methods

February, 2000: SRTM data collected

March, 2000: water levels and samples from village wells

August–November, 2001: Geophysical measurements and additional water samples

July, 2005: repeat water level measurements

Contaminated artesian well at Tian An near Maoming

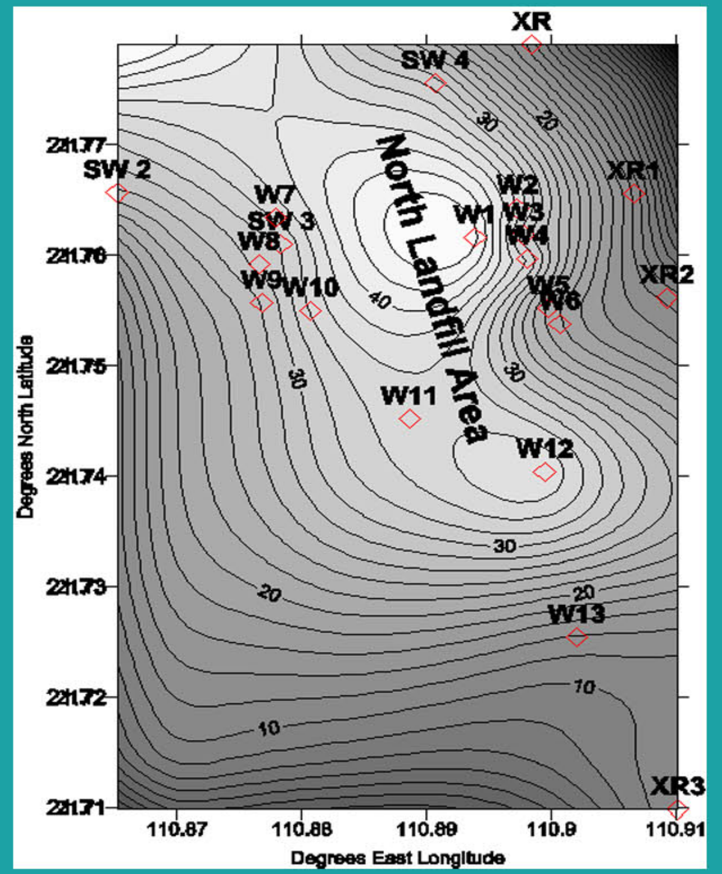
Geology and hydrogeology

Maoming City is located in southeastern China on the southwestern edge of the Maoming basin, a northwest–southeast trending Tertiary fault–bounded syncline 50 km long by about 10 km wide (Yuan and Murray, 1993; Mitchell–Tapping, 1990).

The basin sediments are primarily Tertiary non–marine sandstones, siltstones, mudstones, oil shales, and lignites that dip 5°–13° to the northeast or northwest. The faults bounding the basin trend northwest–southeast and date from the Late Tertiary Himalayan tectonism.

From 1955 to 1995, oil shales within both the Shangcun and Youganwo formations were mined and retorted northwest of Maoming. The production of petroleum and other distillates from the oil shale produced large volumes of waste rock after crushing and retorting. This waste rock was dumped in the two large landfills that flank the oil shale mine pit. Surface and groundwater pollution has resulted from leachate seeping from this waste.

SRTM + Water well data



Water table contours from wells (W) and surface water bodies (SW and XR). SRTM was used to determine all elevations of surface water bodies . This combined data set suggests a groundwater mound beneath the north landfill.

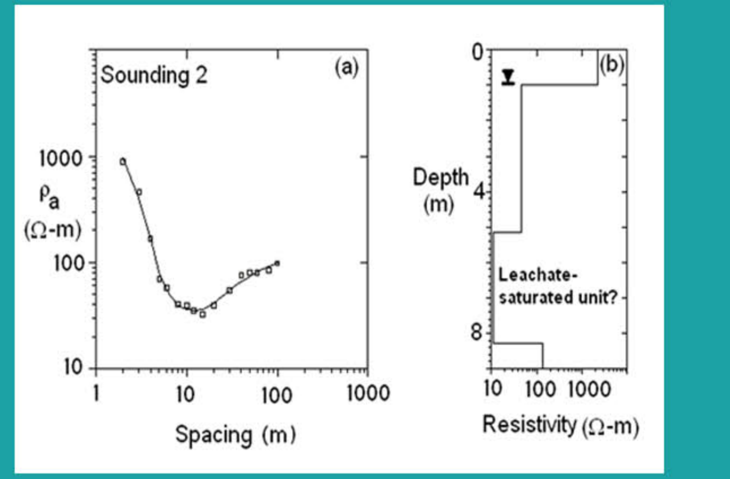
SRTM –– Shuttle Radar Topography Mission (SRTM)

During February 2000 elevation data over 80 percent of the Earth's landmass between 60 degrees North and 56 degrees was collected. Data resolution is 3 arc seconds (about 90 m). Data is displayed as pixels which may be averaged over a surface water body to obtain a mean surface elevation.

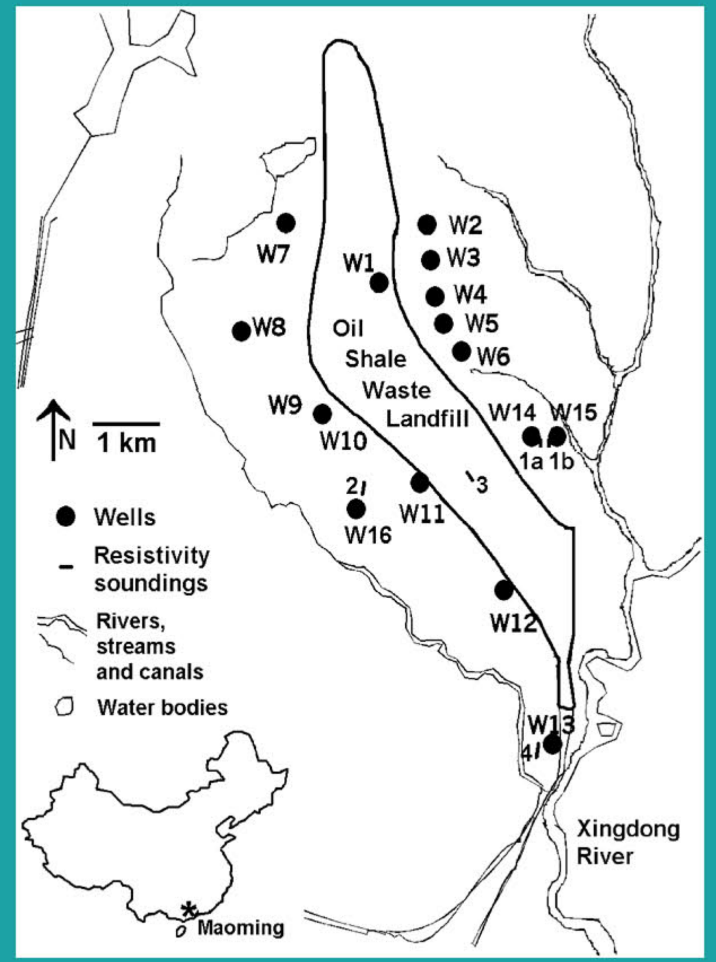
In this study data was obtained from 4 reservoirs around the north landfill and 2 rivers to estimate surface water elevations, which were, in turn, used to help interpolate groundwater levels. Between 10 and 30 pixels were averaged to obtain surface water elevations. Standard deviation of the mean water elevations varied from 0.9–2.2 m.

West side of the north landfill with more recent refuse in the foreground.

Geophysics



Typical resistivity sounding curve and layered model inversion



Conclusions

The Maoming oil shale waste landfills and have a regional impact, making this a scientifically important field site for future environmental studies.

Water well data and mapping of surface water bodies through SRTM suggests more or less radial flow outward from the north landfill into the unconfined aquifer. This has likely contaminated the unconfined aquifer around the north landfill.

Resistivity soundings and contaminated artesian wells suggest contamination of deeper leachate–saturated units as well.

Additional geophysical surveys are needed to further define the extent of contaminated groundwater. Success of these reconnaissance resistivity surveys suggest electrical geophysical techniques would be useful at this site.

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