Taylor & Francis
Taylor & Francis Group

Human and Ecological Risk Assessment: An International Journal

ISSN: 1080-7039 (Print) 1549-7860 (Online) Journal homepage: https://www.tandfonline.com/loi/bher20

A comparison study between previous and current shoreline concentrations of heavy metals at the Great Salt Lake using portable X-ray fluorescence analysis

Marie L. Thorsen, Rod G. Handy, Darrah K. Sleeth, Matthew S. Thiese & Naomi O. Riches

To cite this article: Marie L. Thorsen, Rod G. Handy, Darrah K. Sleeth, Matthew S. Thiese & Naomi O. Riches (2017) A comparison study between previous and current shoreline concentrations of heavy metals at the Great Salt Lake using portable X-ray fluorescence analysis, Human and Ecological Risk Assessment: An International Journal, 23:8, 1941-1954, DOI: 10.1080/10807039.2017.1349541

To link to this article: https://doi.org/10.1080/10807039.2017.1349541

HUMAN AND ECOLOGICAL RISK ASSESSMENT
2017, VOL. 23, NO. 8, 1941–1954
https://doi.org/10.1080/10807039.2017.1349541

Taylor & Francis
Taylor & Francis Group

A comparison study between previous and current shoreline concentrations of heavy metals at the Great Salt Lake using portable X-ray fluorescence analysis

Marie L. Thorsen, Rod G. Handy, Darrah K. Sleeth, Matthew S. Thiese, and Naomi O. Riches

Rocky Mountain Center for Occupational & Environment Health, Department of Family and Preventive Medicine, School of Medicine, University of Utah, Salt Lake City, Utah, USA

ABSTRACT
The Great Salt Lake has been gradually desiccating, increasing the amount of exposed lakebed and potentially exposing heavy metals that may be present in the lakebed soil and sediments. It is hypothesized that there is a statistically significant difference between the current and previous shorelines, with the highest concentrations being at the current shoreline. This study used systematic sampling to collect 32 samples from the current shoreline and previous shorelines (elevation of 1281 and 1282 m, respectively) for a total of 64 samples. All samples underwent X-ray fluorescence analysis to quantify heavy metal concentrations. Nearly all samples contained arsenic (highest concentrations near the current shoreline). The majority of samples (80%) showed mercury levels below the limit of detection (LOD). A statistically significant difference in heavy metal concentrations between the two locations for arsenic, zinc, iron, manganese, rubidium, zirconium, and strontium was found. In addition, it was determined that the relationship between sample size (the number of values above the LOD) and location was statistically significant for mercury, selenium, lead, nickel, copper, manganese, zirconium, and thorium. Further research quantifying heavy metal concentrations in other parts of the Great Salt Lake and the potential for airborne exposures should be conducted.

ARTICLE HISTORY
Received 25 April 2017
Revised manuscript accepted 28 June 2017

KEYWORDS
arsenic; mercury; heavy metal concentrations; soil; Great Salt Lake; lakebed

Introduction

The Great Salt Lake is the largest US inland body of salt water in the Western Hemisphere and, as an endorheic lake, is also one of the most saline bodies of water in the world (Britannica 2016).The salinity of the southern two-thirds of the lake is 11–15%, which is 3 × higher than that of the ocean, and in the northwestern third of the lake, separated by a railroad causeway, the salinity is nearly 25% (USGS 2016a). A high saline environment, such as the Great Salt Lake, makes the perfect home for brine shrimp (*Artemia franciscana*) and

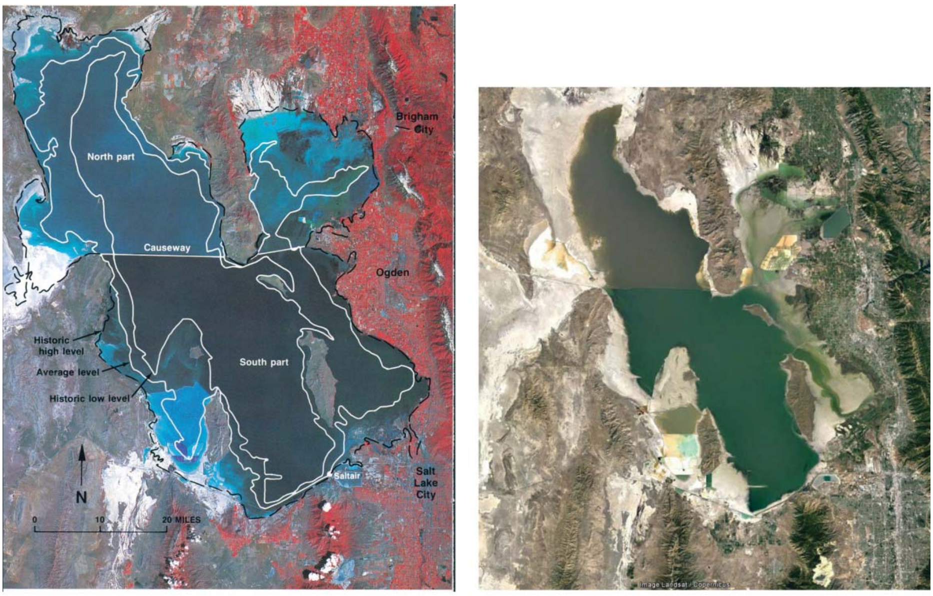
CONTACT Rod G. Handy rod.handy@hsc.utah.edu Rocky Mountain Center for Occupational & Environment Health, Department of Family and Preventive Medicine, School of Medicine, University of Utah, 391 Chipeta Way, Suite C, Salt Lake City, UT 84108, USA.

Color versions of one or more of the figures in this article can be found online at www.tandfonline.com/bher.

brine flies (*Ephydra*) (Britannica 2016; Peterson and Gustin 2008). The brine shrimp and flies at the lake provide an essential food source for the millions of birds migrating on the Pacific Flyway (Aldrich and Paul 2002; USGS 2016b). The lake is surrounded by marshes, mudflats, and islands, that attract many waterfowl such as pelicans, herons, cormorants, terns, and gulls (Britannica 2016). The lake and its surrounding wetlands are recognized as a site of hemispheric importance by the Western Hemisphere Shorebird Reserve Network (Aldrich and Paul 2002), in addition to being home to many different aquatic and terrestrial species (Information on Fishing in Utah 2016; Hunting 2016).

The lake is an important economic and natural resource for the State of Utah (GSL Council). According to a 2012 analysis by Bioeconomics, the Great Salt Lake contributes roughly 1.3 billion dollars annually to Utah's local economy through recreation (birdwatching, boating, hunting), brine shrimp harvesting, mineral extraction, and waste assimilation (Bioeconomics 2012). Given the value of the lake, both as part of the economy and ecosystem (GSL Council), many are concerned about its receding water line and the effects of a shrinking lake (Maffly 2016).

The size of the lake—and the exposed lakebed—fluctuates depending on evaporation rates and the flow of the lake's three main tributaries: Bear River, Weber River, and Jordan River (Britannica 2016). Water levels are primarily the result of snow melt that flows into and out of the lake's tributaries and water diversion of those same rivers (Wurtsbaugh *et al.* 2016). There is some concern that continued water diversion from the connecting rivers for agricultural, industrial, urban, and impounded wetland uses will dry up the lake (Wurtsbaugh *et al.* 2016). The current levels of the lake are near the historic low (USGS 2016c) as indicated in Figure 1.



(a) (b)

Figure 1. Great Salt Lake historic levels and today. (a) A map of the historic high, average and low levels of the lake. Landsat map courtesy of the U.S. Geological Survey. Hassibe, W.R. and Keck, W.G. (1991). The Great Salt Lake. Available at: https://pubs.usgs.gov/gip/70039229/report.pdf) and (b) A map of the Great Salt Lake as of June 2015. Image provided courtesy of Google Earth. Accessed Oct 2016.

On average, the Bear River delivers over 1.2 million acre-ft to the Great Salt Lake each year (Fornataro 2008). However, propositions like the Bear River Project and similar legislations currently under consideration aim to divert water from the Bear River and deliver it to Box Elder, Cache, Weber, Davis, and Salt Lake Counties. The Bear River Project alone will develop up to 220,000 acre-ft of Utah's water rights on the Bear River (Collins 2014). Since the river contributes significantly to the lake, continued diversion is likely to increase the recession of the shoreline (Fornataro 2008).

The receding shoreline poses potential problems beyond economic losses and impacts to the immediate ecosystem: there are precedents for desiccated saline water bodies having adverse effects on communities and the environment. In California, diversion of the Owens River for farming irrigation began in 1913, and by 1926 the Owens Lake was completely dessicated (Owens Dry Lake, California 2016). Outside of the U.S., farm irrigation of the Aral Sea in Central Asia initiated desiccation in the 1960s (Micklin 2007). Lake Urmia in Iran is also threatened by agricultural water diversions and the lake has seen severe reductions in size since 1995 (Wurtsbaugh *et al.* 2012). The desiccation of each of these lakes had negative health effects for the environment and surrounding communities.

Both nationally and internationally, there have been instances (Owens Lake in California, and the Aral Sea in Kazakhstan and Uzbekistan) where lake desiccation preceded increased dust production (Wurtsbaugh *et al.* 2016). Airborne mineral dust can increase hospital visits for those suffering from respiratory and cardiovascular diseases (Grineski *et al.* 2011) and can increase death rates (Giannadaki *et al.* 2014). Since the desiccation of Owens Lake, frequent dust storms of salts, small particles, and elevated concentrations of arsenic and sulfate have been recognized as human health hazards (Levy *et al.* 1999). Wind-blown dust from the exposed lakebeds of the Owens and Mono lakes have caused PM_{10} concentrations that exceed the federal standard of 150 $\mu g/m^3$ in the Owens Valley, Mono Basin, and Mammoth Lakes nonattainment areas (Great Basin Unified Air Pollution Control District 2010). Airborne salt and dust from the dried Aral Sea are thought to contribute to high levels of respiratory illnesses and impairments, eye problems, and throat and esophageal cancer in the near-Aral region (Abdirov *et al.* 1993; Tursunov 1989). There is also speculation that salt and dust blowing from the dried bottom may expose communities to pesticides and heavy metals contained in the lakebed (O'Hara *et al.* 2000).

As the water level of the Great Salt Lake decreases, the amount of exposed lakebed increases, potentially exposing heavy metals such as mercury and arsenic that may be present in the lakebed soil and sediments (Johnson *et al.* 2015; Great Salt Lake Ecosystem Program 2016a). The purpose of this study was to compare the heavy metal concentrations in soil from the current shoreline of the Great Salt Lake to the previous shoreline of approximately 25 years ago.

Human exposure to both arsenic and mercury can occur by means of ingestion, inhalation, and/or dermal contact. Although mercury and arsenic are both naturally occurring in the environment, potentially high levels of arsenic and bioavailable mercury in and around the Great Salt Lake are cause for concern. Inorganic mixtures of arsenic are not uncommon in soil, sediments, and groundwater, but high levels of exposure to inorganic arsenic can cause a variety of symptoms, such as nausea, vomiting, diarrhea, dehydration, and even shock (CDC 2016b). In some cases, long-term exposure to large amounts of inorganic arsenic has been linked with increased risks for diabetes, high blood pressure, and several types of cancer (CDC 2016b).

The most common organic mercury compound in the environment is methylmercury (CDC 2016a). Although methylmercury and elemental mercury vapors are the most harmful forms of mercury, in all its forms (elemental, organic, and inorganic) mercury is known for negatively affecting the nervous system (CDC 2016a). Exposure to high levels of elemental, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus (CDC 2016a). Some effects of exposure are irritability, tremors, changes in vision or hearing, and memory problems (CDC 2016a).

Currently, it is unknown how receding water levels have impacted the concentrations of these and other common heavy metals in the soil of the exposed lakebed. However, exceptionally high methylmercury concentrations have been found in the anoxic deep brine layer of the Great Salt Lake mainly on the south side, ranging from 10 to 100 ng/L (Naftz *et al.* 2008). Shifting of mercury from the deep brine layer to shallow portions of the Great Salt Lake has been demonstrated by directly measuring the mixing that occurs during wind events (Beisner *et al.* 2009). Since the deeper layers of the lake contain higher amounts of mercury, it is hypothesized that the current shoreline will contain higher amounts of heavy metals than the previous shoreline and that there will a statistically significant difference between the two shorelines.

As with other desiccated lakebeds, toxic metals such as mercury and arsenic on the exposed lakebed of the Great Salt Lake could pose potential health problems for the ecosystem and those living and working near the lake. In particular, brine shrimp harvesters are at increased risk due to the nature of their job. Many harvesters work long hours on the lake, and camp in tents or trailers on the shore for weeks at a time (Job Information: Shore Harvester Job 2016). Thus, the purpose of this study was to quantify and compare the levels of mercury and arsenic, as well as other pertinent heavy metals, within the soils on the current and previous shorelines of the Great Salt Lake. Information gathered from this investigation could be used to mathematically model the potential airborne concentrations of various heavy metals and further research could evaluate their subsequent adverse health effects on such worker populations as the brine shrimp harvesters.

Methods

Using a baseline elevation of 1282 m, this study quantified the levels of several heavy metals that pose an environmental and human health concern in the superficial soils at the exposed shoreline of the Great Salt Lake. The elevation of 1282 m represents the estimated average elevation had there been no diversions of the lake's tributaries throughout the years 1847–2015 (Wurtsbaugh *et al.* 2016). It was also once the location of the shoreline in the late 1980 s (USGS 2016c). This comparison location was chosen because it was a considerable distance away from the shoreline (∼6.5 km.) and allowed for easy access. Soil samples were taken from a brine shrimp harvest camp located on the west side of the Great Salt Lake as indicated in Figure 2. According to employees of the Great Salt Lake Ecosystem Program at the Utah Division of Wildlife Resources, these locations are where brine shrimp harvesters stay during the season typically from October to January (Great Salt Lake Ecosystem Program 2017b). However, it should be noted that these are not the exact locations from which the shrimp are harvested, as this is proprietary information.

Brine shrimp harvesters were identified as the most likely population to experience significant exposure to heavy metals contained in the soil should weather patterns and anomalies

Figure 2. Map of Great Salt Lake Sampling Area as of June 2015. The red marker indicates the location of the previous shoreline at an elevation of 1281 m. The yellow marker indicates the location of the sampling location at the current shoreline at an elevation of 1282 m. Image provided courtesy of Google Earth. Accessed Oct 2016.

cause them to become airborne dusts. Soils from the lakebed at an elevation of 1282 m (previous shoreline) were compared to soils from the current shoreline at 1281 m, approximately 6.5 km apart (Currey, Atwood, and Mabey 1984). Figure 2a and b show both the locations in relation to the lake and the markers on the map indicate the elevations. The red marker represents the previous shoreline and the yellow marker represents the current shoreline.

Thirty-two soil samples located at approximately 41.02848333° N, −112.75528333° W were taken from the exposed shoreline of the Great Salt Lake during the fall months of 2016. An additional 32 soil samples were taken at approximately 41.02985000°N, −112.86073333° W at an elevation of 1282 m parallel to where the shoreline samples were collected, during the fall months of 2016. Thus, a total of 64 soil samples were taken, 32 from the prior shoreline and 32 from the current shoreline.

A systematic sampling scheme was used to collect all 64 samples. The sampling protocol and analysis methods were adapted from the Environmental Protection Agency's (USEPA)

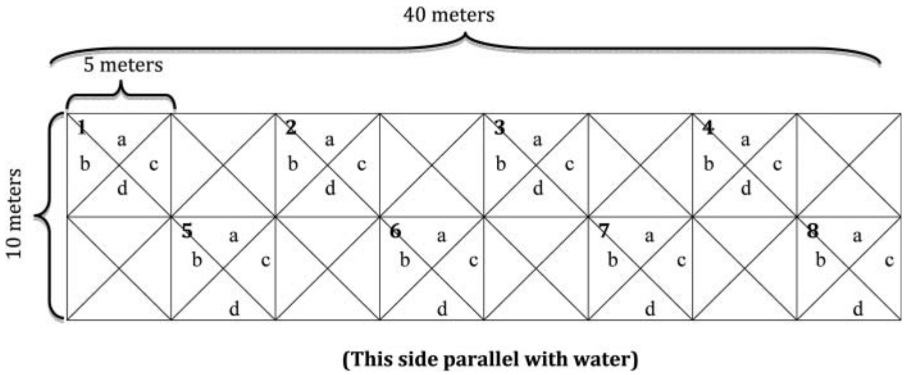
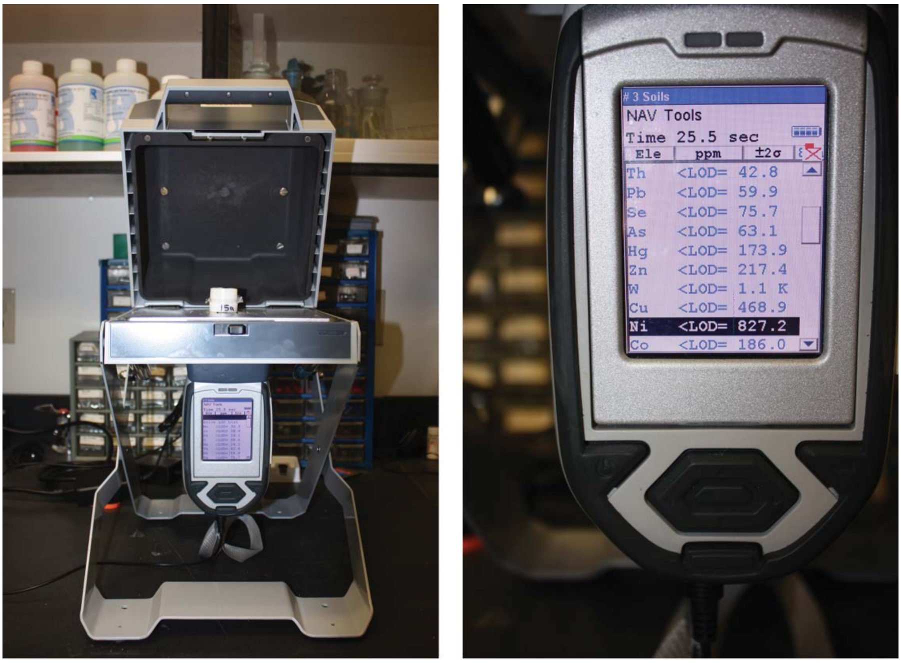


Figure 3. Sampling area dimensions.

6200 method. A sampling area of 10 m × 40 m was identified and then divided up into 16 squares measuring 5 m × 5 m. This systematic sampling scheme was purposely stratified, resulting in a chosen sampling size that was in accordance with the most likely scenario for homogenous soil within each of the 10 m × 40 m areas. Every other square within the 10 m × 40 m area was divided into four sampling sites, where 10.16 cm × 10.16 cm. soil samples were taken from each site for a total of 32 samples. Figure 3 contains a diagram showing the dimensions and configuration of the sampling areas, as well as the location within that grid where samples were taken.

Exact coordinates of the sample locations were determined using a Global Positioning Sytem (Garmin, Olathe, Kansas). Each sample was collected using a spade that was cleaned with a sanitizing wipe (The Clorox Company, Oakland, California) between each sample in order to prevent contamination. Samples were placed in separate plastic bags labeled with the sampling area number and date. After collection, samples were transported to the laboratory for subsequent preparation and analysis. In the lab, each separate sample was dried in a low-humidity desiccator (Sanplatec, Osaka, Japan). The drying process was considered complete when the hygrometer on the dessicator was at the lowest humidity. After drying, samples were ground using a mortar and pestle, and then passed through a 80-μm sieve to achieve a uniform particle size.

Soil samples were analyzed for concentrations of several heavy metals, including mercury and arsenic, using a portable Thermo Fisher Scientific X-ray Fluorescence (XRF) field analyzer (Thermo Fisher Scientific Inc., Waltham, MA). Each processed soil sample was placed in a XRF sample cup, which was then placed inside the protective cover of the XRF stand for analysis. The XRF measures heavy metals in parts per million (ppm), transduced by the instrument after emitting streams of ionizing radiation at the surface/subsurface of the sample and then characterizing the subsequent fluorescent (secondary) X-ray spectrum. Specifically, when an X-ray with energy greater than the atom's K or L shell binding energy hits an atom within the sample, an electron from one of the atom's inner orbital shells dislodges. In order to regain stability, the atom fills the vacancy left in the inner orbital shell with an electron from one of the atom's higher energy orbital shells, thereby causing the electron to drop to the lower energy state by releasing a fluorescent X-ray. The measurement of the energy released is the basis of the XRF analysis. A picture of the analysis process and readout provided by the portable XRF analyzer are shown in Figure 4a and b.



```
# 3 Soils
NAV Tools
Time 25.5 sec
 Ele    ppm     ±2σ
Th   <LOD=  42.8
Pb   <LOD=  59.9
Se   <LOD=  75.7
As   <LOD=  63.1
Hg   <LOD=  173.9
Zn   <LOD=  217.4
W    <LOD=  1.1 K
Cu   <LOD=  468.9
Ni   <LOD=  827.2
Co   <LOD=  186.0
```

(a) (b)

Figure 4. Thermo fisher scientific X-ray fluorescence field analyzer. (a) XRF in the XRF stand with cover and sample in place and (b) readout provided by the XRF.

Statistical methods

Preliminary sampling was carried out near the previous shoreline. Samples were taken back to the lab for analysis to determine the necessary sample size for sufficient statistical power. Iron (Fe) concentrations from the soil samples collected in the initial sampling were assessed in order to conduct power analysis. It was determined that a sample size of 15 was needed for a sufficient power of 0.80, which is standard for studies of this nature (Tan 1996).

Mean and median concentrations, standard deviations, as well as minimum and maximum concentrations of each element were calculated for all soil samples. Sample mean and median concentrations of the analyzed heavy metals from the previous shoreline and current shoreline were compared using a Mann-Whitney-Wilcoxon test, since the data were determined to be not normally distributed. All statistical analyses were performed in Stata^{TM} (StataCorp, College Station, Texas) using an alpha level of 0.05 to determine statistical significance.

Many of the samples were below the LOD and therefore did not provide a quantified concentration measure and could not be analyzed using the planned analysis methods. We decided to conduct a post-hoc analysis using categorical measures of metal concentrations. Each sample at each of the two sampling locations was categorized as being either above or below the LOD. These were then analyzed using chi-squared analyses to determine if there was a statistical difference in the number of readings above the LOD between the two sites. If individual metals had a small number of data points below the LOD (less than 50% of total samples), then values below the LOD were replaced with the LOD divided by 2.

Results

The soil was shown to contain the following elements: arsenic (As), mercury (Hg), selenium (Se), lead (Pb), nickel (Ni), zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), rubidium (Rb), zirconium (Zr), strontium (Sr), thorium (Th), cobalt (Co), and tungsten (W). The results indicated that many samples (>50%) showed heavy metal concentrations that were below the XRF detection limit. Table 1 shows the mean, median, standard deviation, and range of each element for each location. Note that the mean, median, and standard deviation were not calculated for those heavy metals where more than 50% of sampling events did not result in values above the LOD.

For elements such as mercury, selenium, lead, nickel, copper, molybdenum, thorium, cobalt, and tungsten, more than half of the total samples were not included because the concentrations were below the level of detection. However, arsenic was quantified in the overwhelming majority (91%) of the 64 samples that were taken, with the highest mean concentrations found at the current shoreline, closest to the water interface. But, the highest reading of arsenic (27.98 ppm) was found at the current shoreline. As for mercury, 80% of the 64 samples showed concentration levels below the LOD. The only detectable levels of mercury were found at the previous shoreline, with the highest reading approximately 10 ppm. Only 13% of samples taken at the previous shoreline contained selenium while

Table 1. Comparison of mean, median, standard deviation, and range of heavy metal concentrations.

Element	Location	N	% Below LOD	Mean (ppm)	Median (ppm)	SD	Min	Max
As	Previous	32	0	9.79	10.07	1.86	6.43	14.47
	Current	29	09	13.14	12.88	4.17	7.45	27.98
Hg	Previous	11	66	—	—	—	6.61	10.85
	Current	2	94	—	—	—	8.96	9.86
Se	Previous	4	87	—	—	—	3.42	4.99
	Current	0	100	—	—	—	—	—
Pb	Previous	7	78	—	—	—	9.56	13.99
	Current	17	47	13.14	12.92	2.98	9.95	23.39
Ni	Previous	16	50	47.40	46.57	7.21	37.38	59.64
	Current	1	97	—	—	—	45.19	45.19
Zn	Previous	32	0	80.86	78.92	10.92	63.51	106.32
	Current	30	06	21.53	22.36	4.98	13.39	32.60
Cu	Previous	17	47	22.80	21.44	3.39	19.21	31.07
	Current	2	94	—	—	—	24.39	25.52
Fe	Previous	32	0	12633.44	12416.50	1292.01	10391.64	14976.81
	Current	32	0	629.41	683.65	258.15	102.96	1199.99
Mn	Previous	32	0	354.078	353.77	33.47	290.69	423.99
	Current	18	44	65.62	60.60	15.44	48.44	103.91
Mo	Previous	4	87	—	—	—	5.40	6.21
	Current	1	97	—	—	—	12.74	12.74
Rb	Previous	32	0	86.71	84.30	7.72	73.3	101.04
	Current	32	0	9.57	9.77	1.89	5.85	12.93
Zr	Previous	32	0	175.21	168.08	32.23	133.51	287.55
	Current	26	18	28.00	25.56	9.84	12.86	59.22
Sr	Previous	32	0	538.85	532.43	40.68	475.98	624.11
	Current	32	0	2307.37	2531.34	706.18	580.54	3205.30
Th	Previous	32	0	10.59	10.44	1.80	6.43	14.92
	Current	0	100	—	—	—	—	—
Co	Previous	1	97	—	—	—	99.45	99.45
	Current	0	100	—	—	—	—	—
W	Previous	1	97	—	—	—	43.29	43.29
	Current	1	97	—	—	—	49.64	49.64

Table 2. Comparison of mean, median, standard deviation, and range of arsenic and zinc concentrations (with values below LOD imputed).

Metal	Location	$N =$	Mean (ppm)	Median	SD	Min	Max
As	Previous	32	9.79	10.07	1.86	6.43	14.47
	Current	32	12.24	12.15	4.85	3.53	27.98
Zn	Previous	32	80.86	78.92	10.92	63.51	106.32
	Current	32	20.55	21.08	6.15	5.80	32.60

none of the samples taken at the current shoreline had any detectable amounts. Very few samples at the previous shoreline contained lead (21%). The majority of samples containing lead were found at the current shoreline (53%), while most of the samples containing nickel and copper were found at the previous shoreline. All of the samples taken from the previous shoreline contained manganese and zirconium and over half of the samples at the current shoreline contained manganese (56%) and zirconium (82%). Quantifiable levels of zinc, iron, rubidium, and strontium were found in nearly all of the samples characterized (90–100%).

Table 2 shows the mean, median, standard deviation, and range of the concentration values of arsenic and zinc with imputed values. Arsenic and zinc both had a significant number of data points above the LOD (more than 90% of total samples). In Table 2, the values below the LOD for arsenic and zinc were replaced with the LOD divided by 2.The LOD was provided by the reading on the XRF. There was little difference between the mean concentration before imputation (13.14 ppm for arsenic and 21.53 ppm for zinc) and after (12.24 ppm for arsenic and 20.55 ppm for zinc). The values after imputation were slightly lower as shown in Table 2. In Table 3, the Mann–Whitney–Wilcoxon results are shown, comparing the two locations only for the heavy metals that had a significant number of data points above the LOD. For arsenic and zinc, a Mann–Whitney–Wilcoxon test was also performed after imputation of values below the LOD. As seen in Table 3, there was a statistically significant difference between the two locations for concentrations of arsenic ($p \leq .001$), zinc ($p \leq .001$), iron ($p \leq .001$), manganese ($p \leq .001$), rubidium ($p \leq .001$), zirconium ($p \leq .001$), and strontium ($p \leq .001$). Arsenic and zinc were also shown to have a statistically significant p-value after imputing for values below the LOD ($p = .0029$ and $p \leq .001$). All of the metals shown in Table 3 showed significantly higher concentrations at the previous shoreline with the exception of arsenic and strontium. After accounting for the imputed values for arsenic and zinc, there was still a significant difference between the two locations.

In Table 4, a chi-square test of independence was performed to examine the relationship between sample size (the number of samples with concentrations above the LOD) and

Table 3. Statistical significance comparison of heavy metals between two locations (excluding metals with >50% of data points below the LOD).

Metal	p-Value	p-Value (imputed)	Shoreline with >mean and median
As	< 0.001	0.0029	Current
Zn	< 0.001	< 0.001	Previous
Fe	< 0.001	—	Previous
Mn	< 0.001	—	Previous
Rb	< 0.001	—	Previous
Zr	< 0.001	—	Previous
Sr	< 0.001	—	Current

Table 4. Statistical significance comparison between number of values >LOD and location (Chi-square).

Metal	*p*-Value (chi square)	Shoreline with >sample size
As	0.076	Previous
Hg	0.005	Previous
Se	0.039	Previous
Pb	0.010	Current
Ni	< 0.001	Previous
Zn	0.151	Previous
Cu	< 0.001	Previous
Fe	—	—
Mn	< 0.001	Previous
Mo	0.162	Previous
Rb	—	—
Zr	0.010	Previous
Sr	—	—
Th	< 0.001	Previous
Co	0.313	Previous
W	1.000	—

location for each metal. The relationship between sample size and location was significant for mercury ($p = .005$), selenium ($p = .039$), lead ($p = .010$), nickel ($p \leq .001$), copper ($p \leq .001$), manganese ($p \leq .001$), zirconium ($p = .010$), and thorium ($p \leq .001$). Of those metals, there was shown to be a larger number of samples with concentrations above the LOD at the previous shoreline for the following: mercury, selenium, nickel, copper, manganese, zirconium, and thorium. Lead was the only metal to have a higher number of samples with concentrations above the LOD at the current shoreline. Arsenic ($p = .076$), zinc ($p = .151$), molybdenum ($p = .162$), and cobalt ($p = .313$) had relatively similar samples sizes at each shoreline location and therefore the relationship between the two variables was not statistically significant. If a metal was found in all samples at both shorelines, then they were excluded from the table.

Discussion

A comparison was made between the heavy metal concentrations in soil from the current shoreline of the Great Salt Lake to the previous shoreline of approximately 25 years ago. It was hypothesized that there would be a statistically significant difference between the heavy metal concentrations at both sites and that higher concentrations of heavy metals would be present at the current shoreline. The logic underpinning the study hypothesis was that, over time much of the anthropogenic and natural surface/subsurface heavy metal concentrations would have dissipated due to being transported away from their shore of origin via winds and climatic anomalies. In regard to the hypothesis, however, the results were mixed. Samples collected at the current shoreline contained higher concentrations of arsenic (the mean at the current shoreline was 13.14 ppm while the mean at the previous shoreline was 9.79 ppm), but based upon the number of samples found with detectable amounts of mercury, there was more mercury at the previous shoreline, the area furthest from the water interface. Some concentrations of mercury were present near the current shoreline, but not in appreciable amounts. Although only seven of the sixteen metals found in the soil had enough data points to compare the ppm concentrations at each shoreline, all seven were shown to have a significant relationship between concentration and location. Of those metals, all of them (except for arsenic and strontium) were found to have greater concentrations at the previous shoreline.

After replacing missing values for arsenic and zinc, the mean concentration was relatively similar with a difference of less than 1 ppm. The results when comparing the relationship between concentration and the two locations was also similar to results before imputation. Overall, replacing missing values with the LOD/2 for metals that had only a few values missing (<10%) did not make a significant difference in the results.

The number of observed values above the LOD was statistically significantly higher ($p \leq .05$) at the previous shoreline for arsenic, mercury, selenium, nickel, zinc, copper, manganese, molybdenum, zirconium, thorium, and cobalt. Lead was the only metal found to have a significantly higher number of observed values above the LOD at the current shoreline. Overall, with the exception of arsenic, lead, and strontium, the heavy metals were found to have higher concentrations and/or more detectable values at the previous shoreline, which was contrary to what was originally expected. The purpose of this study was to characterized several heavy metal concentrations, and it does not go into depth about the reasoning behind heavy metal contamination in the soil, but we do hypothesize possible explanations for the difference in concentration and detectable amounts of metal at each shoreline. The previous shoreline, having been uncovered for the past twenty years, has been more exposed to wind events and dust storms which may have contributed to the difference in concentrations of heavy metals. The difference in concentrations of heavy metals on the two shorelines could also be somewhat explained by looking at the history of pollution of the lake. Starting in the late 1800s, mining, smelting, and other industrial activities caused an increase of air and water pollution in Utah (Wurtsbaugh *et al.* 2012). In the early to mid 1900s there was an increase in production of heavy metals from smelters in the Salt Lake area, and by the late 1900s regulations involving discharge of heavy metals into the lake and rivers feeding into the lake, were established, as well as improvements in smelting techniques (Wurtsbaugh *et al.* 2012). The efforts in the 1970s to decrease pollution and the change in smelting techniques could have decreased the heavy metal content in the water and subsequently the soil and sediments left behind. Therefore, the water at the time of the previous shoreline, could have been more contaminated with heavy metals than the water now. The increase in lead and arsenic at the current shoreline could indicate that these two heavy metals have increased in concentration in the water in the past 20 years. More research into the history of the GSL and the metals involved in the industrial processes in areas surrounding the lake should be considered in future research.

Although the values for mercury were relatively low (*i.e.*, below 10 ppm), further research characterizing the soil concentrations for heavy metals further away from the lake in that area should be conducted. Research looking at multiple locations between the two shorelines should be done, as well, to determine if there are concentration gradients to be observed. During each sample collection event it was also noted that rifle/pistol shooting and ATV riding close to the previous shoreline were occurring and generating significant amounts of dust; thus, this may be an area to look at in the future.

Overall, the soil found at the previous shoreline was fairly similar to elemental heavy metal concentrations of soils found throughout the Western United States. A geological survey completed by the US Department of the Interior showed numerous heavy metal concentrations across the United States. For the western United States the average amount of arsenic in soil was 5.5 ppm, which is slightly lower than what was found near the lake.

Mercury was also measured at levels higher than the average of 0.046 ppm (Shacklette and Boerngen 1984). This result seems to support other studies involving localized levels of mercury in and around the Great Salt Lake. For example, large quantities of mercury have been found in the deep levels of the lake's water (Johnson *et al.* 2015; Naftz *et al.* 2008) and in certain waterfowl that eat brine shrimp and flies such as Common Goldeye, Cinnamon Teal, and Northern Shoveler ducks (Naftz *et al.* 2008; Utah Waterfowl Advisories 2016). In addition, a few previous studies have examined the concentration levels of selenium, arsenic, and mercury in the wetlands that surround the lake near the Salt Lake City airport, which have found very low concentrations (Dicataldo *et al.* 2011; Naftz *et al.* 2011). However, little research has looked at the concentration of heavy metals in the exposed soil in and around the lakebed, especially on the west side.

In late 2016, after the completion of all of this study's sampling events, the State of Utah began breaching the Union Pacific Railroad causeway that separates the north and south arms of the Great Salt Lake (Utah Department of Natural Resources 2016). The north arm has a lower elevation than the south arm and a much higher salinity (USGS 2016c). The breach of the causeway will likely cause a decrease in elevation of the lake and an increase of the lakebed in the southern portion (Utah Department of Natural Resources 2016). Future research should evaluate any effects the breach of the causeway may have on the lake elevation and heavy metal concentrations in both the soil and water.

Conclusion

This comparison study characterized several heavy metal concentrations at the past and current shorelines of the Great Salt Lake with a portable XRF analyzer. The soil was shown to contain arsenic, mercury, selenium, lead, and several other less toxic metals. Many of the samples (>50%) showed heavy metal concentrations that were below the XRF detection limit. Arsenic was quantified in the majority (91%) of the samples that were taken. As for mercury, 80% of the samples showed concentration levels below the LOD. Very few of the samples contained selenium (6%). Very few samples at the previous shoreline contained lead (21%) and the majority of lead-containing samples were found at the current shoreline (53%). Results indicate the current shoreline had significantly higher concentrations of arsenic in the soil than the previous shoreline. However, for two of the other more toxic metals characterized, mercury and lead, there was not a significant difference between the concentrations measured at either sampling location. The relationship between sample size (number of data points above the LOD) and location was significant for the more toxic metals such as mercury ($p = .005$), selenium ($p = .039$), and lead ($p = .010$) and several other less toxic metals. All of the metals were found to have a higher number of data points above the LOD at the previous shoreline except for lead. Despite mixed support for the study hypothesis, future studies have been planned and include comprehensively characterizing various heavy metals from the former and current shorelines and development of a human exposure model to assess airborne heavy metals in worker populations occupying proximate locations to the Great Salt Lake shoreline.

Acknowledgments

The authors wish to thank Tracy Rees for editorial and writing assistance.

Funding

This study was funded in part by the National Institute for Occupational Safety and Health under grant # T42OH008414-10.

References

Abdirov CA, Agadzhanyan NA, Vervikhvost AV, *et al.* 1993. Stress reaction of healthy children of nukus from the effects of ecological factors in priaral'ye. Vestn Karakalp Otdel Akad Nauk Resp Uzb 2:15–20

Aldrich TW, and Paul DS. 2002. Avian ecology of Great Salt Lake. In Great Salt Lake: an overview of change. https://scholar.google.com/scholar?hl=en&q=Aldrich%2C+T.W.+and+D.S.+Paul.+2002.+Avian+ecology+of+Great+Salt+Lake.+In+Great+Salt+Lake%3A+an+overview+of+change+%28J.W.+Gwynn%2C+ed.%29.+Utah+Geological+Survey%2C+Department+of+Natural+Resources+Special+Publication+2002.&btnG = &as_sdt = 1%2C3&as_sdtp=

Beisner K, Naftz DL, Johnson WP, *et al.* 2009. Selenium and trace element mobility affected by periodic displacement of stratification in the Great Salt Lake, Utah. Sci Tot Environ 407(19):5263–73. doi:10.1016/j.scitotenv.2009.06.005

Bioeconomics. 2012. Economic significance of the Great Salt Lake to the State of Utah. State of Utah Great Salt Lake Advisory Council, Salt Lake City, Utah. 50p. http://www.gslcouncil.utah.gov/docs/2012/Jan/GSL_FINAL_REPORT-1-26-12.PDF

Britannica. 2016. Great Salt Lake. Britannica. Accessed December 22. https://www.britannica.com/place/Great-Salt-Lake

CDC. 2016a. ATSDR – ToxFAQs^{TM}: Mercury. Accessed December 31. https://www.atsdr.cdc.gov/toxfaqs/TF.asp?id=113&tid=24#bookmark05

CDC. 2016b. CDC – NBP – Factsheet – Arsenic. Accessed December 31. https://www.cdc.gov/BIOMONITORING/Arsenic_FactSheet.html

Collins B. 2014. Bear River Pipeline Concept Report, Vol. 1

Currey D, Atwood G, and Mabey D. 1984. Major levels of Great Salt Lake and Lake Bonneville. State of Utah Department of Natural Resources. http://files.geology.utah.gov/online/m/m-73.pdf

Dicataldo G, Johnson WP, Naftz DL, *et al.* 2011. Diel variation of selenium and arsenic in a Wetland of the Great Salt Lake, Utah. Appl Geochem 26(1):28–36. doi:10.1016/j.apgeochem.2010.10.011

Fornataro EA. 2008. The last untapped river in Utah: An argument against the development of the Bear River. J Land Resour Environ Law 28:141–62

Giannadaki D, Pozzer A, and Lelieveld J. 2014. Modeled global effects of airborne desert dust on air quality and premature mortality. Atmos Chem Phys 14(2):957–68. doi:10.5194/acp-14-957-2014

Great Basin Unified Air Pollution Control District. 2010. 2010 Ambient Air Monitoring Network Plan For National Core (NCORE) Monitoring Station. April. https://www3.epa.gov/ttn/amtic/files/networkplans/CAGreatBasinPlan2010.pdf

Great Salt Lake Ecosystem Program. 2016a. Accessed December 30. https://wildlife.utah.gov/gsl/facts/heavy_metals.php

Great Salt Lake Ecosystem Program. 2017b. Brine Shrimp Harvester Information. Accessed February 6. https://wildlife.utah.gov/gsl/harvest/information.php

Grineski SE, Staniswalis JG, Bulathsinhala P, *et al.* 2011. Hospital admissions for asthma and acute bronchitis in El Paso, Texas: Do age, sex, and insurance status modify the effects of dust and low wind events? Environ Res 111(8):1148–55. doi:10.1016/j.envres.2011.06.007

GSL Council. n.d. http://www.gslcouncil.utah.gov/docs/2012/Feb/gslac_eco_sig.PDF

Hunting. 2016. Accessed December 23. https://wildlife.utah.gov/hunting-in-utah.html

Information on Fishing in Utah. 2016. Accessed December 23. https://wildlife.utah.gov/fishing-in-utah.html

Job Information: Shore Harvester Job. 2016. Accessed December 30. https://www.appone.com/MainInfoReq.asp?R_ID=1339602

Johnson WP, Swanson N, Black B, *et al.* 2015. Total- and methyl-mercury concentrations and methylation rates across the freshwater to hypersaline continuum of the Great Salt Lake, Utah, USA. Sci Tot Environ 511(April):489–500. doi:10.1016/j.scitotenv.2014.12.092

Levy DB, Schramke JA, Esposito KJ, *et al.* 1999. The shallow ground water chemistry of arsenic, fluorine, and major elements: eastern Owens Lake, California. Appl Geochem 14(1):53–65. doi:10.1016/S0883-2927(98)00038-9

Maffly B. 2016. Great Salt Lake at near-record low level|the Salt Lake Tribune. Accessed December 30. http://www.sltrib.com/home/2107813-155/great-salt-lake-at-near-record-low

Micklin P. 2007. The Aral Sea disaster. Annu Rev Earth Planet Sci 35(1):47–72. doi:10.1146/annurev.earth.35.031306.140120

Moore JN. 2016. Recent desiccation of western great basin saline lakes: lessons from Lake Abert, Oregon, U.S.A. Sci Tot Environ 554–555 (June):142–54. doi:10.1016/j.scitotenv.2016.02.161

Naftz D, Angeroth C, Kenney T, *et al.* 2008. Anthropogenic influences on the input and biogeochemical cycling of nutrients and mercury in Great Salt Lake, Utah, USA. Appl Geochem 23(6):1731–44. doi:10.1016/j.apgeochem.2008.03.002

Naftz DL, Cederberg JR, Krabbenhoft DP, *et al.* 2011. Diurnal trends in methylmercury concentration in a wetland adjacent to Great Salt Lake, Utah, USA. Chem Geol Diel Biogeochem Process Terrestr Waters 283(1–2):78–86. doi:10.1016/j.chemgeo.2011.02.005

O'Hara SL, Wiggs GFS, Mamedov B, *et al.* 2000. Exposure to airborne dust contaminated with pesticide in the Aral Sea region. Lancet 355(9204):627–28. doi:10.1016/S0140-6736(99)04753-4

Owens (Dry) Lake, California. 2016. Accessed December 22. https://geochange.er.usgs.gov/sw/impacts/geology/owens/

Peterson C and Gustin M. 2008. Mercury in the air, water and biota at the Great Salt Lake (Utah, USA). Sci Tot Environ 405(1–3):255–68. doi:10.1016/j.scitotenv.2008.06.046

Shacklette HT and Boerngen JG. 1984. Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States. No. 1270. USGPO. https://www3.epa.gov/ttn/chief/old/ap42/ch11/s03/reference/bref22_c11s03_ch4_1997.pdf

Tan KH. 1996. Soil Sampling, Preparation, and Analysis. New York: Marcel Dekker

Tursunov AA. 1989. The Aral Sea and the ecological situation in Central Asia and Kazakhstan. Hydrotechn Construct 23(6):319–25. doi:10.1007/BF01424066

USGS. 2016a. USGS Utah Water Science Center: Great Salt Lake. Accessed December 23. http://ut.water.usgs.gov/greatsaltlake/salinity/

USGS. 2016b. USGS Utah Water Science Center: Great Salt Lake. Accessed December 23. http://ut.water.usgs.gov/greatsaltlake/shrimp/

USGS. 2016c. USGS Utah Water Science Center: Great Salt Lake Elevations and Elevation Changes. Accessed December 27. http://ut.water.usgs.gov/greatsaltlake/elevations/

Utah Department of Natural Resources. 2016. Union Pacific Railroad Causeway Breach to Proceed after Dec. 1. Accessed December 30. https://naturalresources.utah.gov/dnr-newsfeed/union-pacific-railroad-causeway-breach-to-proceed

Utah Waterfowl Advisories. 2016. Accessed December 29. http://waterfowladvisories.utah.gov/

Wurtsbaugh W. 2012. Paleolimnological Analysis of the History of Metals Contamination in the Great Salt Lake, Utah. March. http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1555&context=wats_facpub&sei-redir=1&referer=http%3A%2F%2Fwww.bing.com%2Fsearch%3Fq%3Dhistoric%2Bmetal%2Bdespostion%2Bin%2Bgreat%2Bsalt%2Blake%26src%3DIE-TopResult%26FORM%3DIETR02%26conversationid%3D#search=%22historic%20metal%20despostion%20great%20salt%20lake%22

Wurtsbaugh W, Marcarelli Amy M. and Boyer Greg L. 2012. Eutrophication and Metal Concentrations in Three Bays of the Great Salt Lake (USA), February. http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1627&context=wats_facpub

Wurtsbaugh W, Miller Craig, Null Sarah, *et al.* 2016. Impacts of Water Development on Great Salt Lake and the Wasatch Front, February. http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article = 1891&context = wats_facpub