
Chapter 10

ARSENIC CONCENTRATIONS IN THE NELLIS DUNES RECREATION AREA

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1. Introduction

Chemical analyses were performed on soil and airborne sediment from all 17 surface units in the Nellis Dunes Recreation Area (NDRA). An overview of the results is provided in Chapter 9. However, one particular chemical element (arsenic) is of special concern because it occurs in exceptionally high concentrations in several surface units, much higher than reported in the scientific literature on arsenic in the western United States published to date. Exposure to arsenic constitutes an important health risk. Arsenic has been strongly linked to a long list of diseases such as heart disease, hypertension, peripheral vascular disease, diabetes, immune suppression, acute respiratory infections, intellectual impairment in children, and skin, lung, prostate, bladder, kidney and other cancers (Chen et al., 1992; Abernathy et al., 1999; Järup, 2003; Tseng et al., 2003; von Ehrenstein et al., 2006). Additionally, arsenic has been found to be uniquely harmful to lung tissue by inhibiting wound repair and altering genes associated with immune functions in lung tissue (Olsen et al., 2008; Kozul et al., 2009a; Kozul et al., 2009b). It is one of the most poisonous chemical elements naturally occurring on the Earth's surface.

The occurrence of high arsenic concentrations in the Nellis Dunes Recreation Area is of great concern for several reasons. First, arsenic is usually associated with, and attached to, the fine particle fraction of the soil (Chen et al., 1999; Van Pelt and Zobeck, 2007). It

is this fraction in particular that is emitted by wind erosion or off-road vehicular (ORV) activity. Depending on the arsenic concentrations in the topsoil, the capacity of that topsoil to produce dust and the degree of disturbance of the top layer by either wind erosion or ORV activity, large to very large amounts of arsenic may be emitted from the soil. Secondly, once emitted the arsenic is transported downwind, it can settle to the ground and pollute other areas within the NDRA originally not characterized by high arsenic concentrations. Third, runoff and water erosion in the arsenic source areas bring substantial amounts of arsenic to the washes, where it is transported downstream. Several of the major washes in the NDRA are characterized by high concentrations of arsenic even at places several km downstream from the arsenic sources. These places behave as secondary sources when they dry and material is reemitted into the air. Finally, the number of visitors potentially exposed to arsenic emissions in NDRA is very high. A report published in 2004 (BLM, 2004) mentions a number of 285,000 visitors annually, but ORV activity in the region has quadrupled since then (Spivey, 2008).

For all these reasons a separate chapter on arsenic is provided in this report. It describes the occurrence, concentrations and emissions of arsenic in the NDRA, but does **NOT** consider the potential health impacts. A preliminary study was carried out using mice to model the impact NDRA dust might have on the human immune system (see Chapter 11). However, in order to more fully understand what the potential human health risks might be, a separate study is required. Such a study should include measurements of the actual amounts of arsenic and other chemicals and minerals contained within the dust inhaled by NDRA visitors during ORV activity and wind erosion, toxicological analysis of the impact of the inhaled dust to the human body, and a full risk analysis of all 17 surface units occurring in the NDRA. The original task agreement of the Nellis Dunes project did not include such a risk study because the high amounts of arsenic were only discovered during the project, and the budget did not allow adding a detailed risk analysis to the study. In addition, if needed, a second, separate study would be required to define the health risk the dust at NDRA might pose to the population in Clark County.

2. Sample collection

Soil samples were taken from all 17 surface units occurring in the NDRA. They included dust stations, locations where experiments with the off-road vehicles were carried out, and five supplementary sampling spots located on the major parking areas. All soil samples were taken from the upper 2-3 cm of the topsoil.

Additional airborne dust samples were collected from all ORV spots and from the five parking areas using the Portable In Situ Wind Erosion Laboratory or PI-SWERL (see Chapter 4 for a description of the instrument). The PI-SWERL was set to an RPM of 6000 and the dust emitted was collected by connecting a Dyson vacuum cleaner to the

3. Laboratory procedure

The *soil samples* were air dried and sieved to remove coarse fragments (>2 mm). The <2 mm fraction was then digested in accordance with EPA Method 3052 (USEPA, 1996). The digested samples were initially scanned for 66 different elements using inductively coupled plasma mass spectroscopy (ICP-MS). The purpose of the initial semi-quantitative scan was to identify elements of potential environmental concern in the samples. Based on the results of the semi-quantitative scan, the following elements were identified as elements of potential concern: arsenic (As), cobalt (Co), chromium (Cr), cesium (Cs), copper (Cu), cadmium (Cd), silver (Ag), nickel (Ni), lead (Pb), strontium (Sr), uranium (U), vanadium (V), thallium (Tl), boron (B), molybdenum (Mo), antimony (Sb), and mercury (Hg). The samples were then re-analyzed quantitatively for these elements using ICP-MS.

To ensure quality control for the ICP-MS analyses, Buffalo River Sediment Reference Material 8704 was obtained from the National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, USA. Samples of this material were digested in accordance with EPA Method 3052 and analyzed along with the NDRA samples. Satisfactory recoveries were found for the trace elements analyzed.

For the *PI-SWERL samples* a separate analysis was performed for the <10 μm (PM10) and 10-60 μm size fractions. The procedure was as follows. First, in order to not lose any soluble elements during wet sieving, 10:1 water:soil extracts were prepared to determine the water soluble constituents in the PI-SWERL samples. The 10:1 extracts were used instead of a saturated paste because of limited sample sizes. These samples were allowed to sit overnight and were then filtered to obtain the supernatant. The supernatant solution was analyzed by ICP-MS. Once this was completed, the <10 μm and 10-60 μm fractions were separated by sedimentation and wet sieving and digested in accordance with EPA Method 3052 prior to analysis. The 60 μm limit was used as a cut-off for total suspendable particles (TSP), because it represents the maximum size of grains that will still be transported in short-term suspension during average wind speed and turbulence (see Pye and Tsoar, 1990). It also nearly coincides with the maximum diameter of silt (52 μm or 63 μm , depending on which criterion is used; see Goossens and Buck, 2009 for more information). Although all of the samples were analyzed for the potential elements of environmental concern, this chapter focuses exclusively on the arsenic concentrations. The remaining elements were already addressed in Chapter 9.

4. Results

The reported concentrations of arsenic (As) in the surface unit and parking lot *soil samples* ranged from 3.49 to 83.02 $\mu\text{g g}^{-1}$ or parts per million (ppm; Table 1). The highest concentrations of As in the soil samples occurred within the silt/clay areas (surface units 2.1 to 2.4), the drainages (surface units 4.1 to 4.3), and surface unit 1.5.

Table 1: Arsenic concentrations in the soil samples at NDRA. Particles coarser than 2 mm were removed from the samples prior to analysis.

Surface Unit Description	As ($\mu\text{g g}^{-1}$)
<u>USEPA Regional Screening Levels⁽¹⁾</u>	
Residential Soil	0.39
Groundwater Protection	0.0013
<u>Sand and Sand-Affected Areas</u>	
1.1: Dunes with no vegetation	4.37
1.2: Dunes with vegetation	3.49
1.3: Disturbed sand surfaces	6.74
1.4: Patchy layers of sand over silty/rocky subsoil	4.92
1.5: Outcrops of very fine sand and coarse silt	46.06
<u>Silt/clay Areas</u>	
2.1: Silt/clay with crust	19.71
2.2: Silt/clay with gravel	83.02
2.3: Aggregated silt deposits	11.01
2.4: Disturbed silt surfaces	11.79
<u>Rock-covered Areas</u>	
3.1: Desert pavements	13.56
3.2: Rock-covered surfaces with silt/clay zones	7.89
3.3: Rock-covered surfaces with sandy loam	6.85
3.4: Rock-covered surfaces with encrusted sand	7.28
3.5: Bedrock and/or petrocalcic horizons	9.03
<u>Drainage Areas</u>	
4.1: Gravelly drainages	32.36
4.2: Gravel and sand drainages	23.39
4.3: Gravel and silt/clay drainages	31.45
<u>Parking Lot Areas</u>	
North Parking Lot #1	5.98
South Parking Lot #1	4.88
South Parking Lot #2	6.86
Southeast Parking Lot #1	17.62
<u>Standard Samples</u>	
BRS	14.64
Buffalo River Reference Material 8704	17

Notes:

(1) The Screening Levels (SLs) are developed using risk assessment guidance from the EPA Superfund program and are used for site “screening” and as initial cleanup goals, if applicable. The groundwater protection concentrations shown are soil concentrations considered to be protective of groundwater resources.

(2) NA = Not applicable

The As concentrations in the PM₁₀ and 10-60 μm fractions in the *PI-SWERL* samples ranged from 18.56 to 290.01 and from 16.13 to 312.42 $\mu\text{g g}^{-1}$, respectively (Table 2). Note that these values only reflect arsenic that was not soluble in water. The highest As concentrations in both size fractions were reported in the samples collected from

undisturbed terrain of surface unit 1.5; the lowest concentrations occurred in the undisturbed terrain samples from surface unit 3.2. Elevated As concentrations (41.13 to 161.32 $\mu\text{g g}^{-1}$; Table 2) also occurred in the ORV trails and undisturbed terrain samples from surface units 2.1, 2.2, 4.1, 4.2, and 4.3.

The *water-soluble As concentrations* in the 0-60 μm fractions of the PI-SWERL samples ranged from 0.42 to 14.71 $\mu\text{g g}^{-1}$ (Table 3). The pH values of the soluble PI-SWERL extracts were near-neutral to slightly alkaline, ranging from 6.58 to 9.11 (Table 3). Electrical conductivity (EC) values of the extracts were from 0.06 to 2.43 dS m^{-1} . The EC values document the salinity of most of the soils in the NDRA, particularly when considering that the extracts were diluted by a factor of 10:1.

Table 2: Arsenic concentrations in airborne (PI-SWERL) samples. Surface unit 3.5 (bedrock) was not sampled.

Surface Unit Description	Particle Size (μm)	As ($\mu\text{g g}^{-1}$)
<u>USEPA Regional Screening Levels⁽¹⁾</u>		
Residential Soil		0.39
Groundwater Protection		0.0013
<u>Sand and Sand-Affected Areas</u>		
1.1R ⁽²⁾ : Dunes with no vegetation	<10	43.31
	10 to 60	30.40
1.1NR ⁽³⁾	<10	46.56
	10-60	28.37
1.2R: Dunes with vegetation	<10	52.45
	10 to 60	42.14
1.2NR	<10	48.78
	10 to 60	36.55
1.3R: Disturbed sand surfaces	<10	54.14
	10 to 60	46.34
1.3NR	<10	37.96
	10-60	30.37
1.4R: Patchy layers of sand over silty/rocky subsoil	<10	26.32
	10 to 60	20.46
1.4NR	<10	27.21
	10 to 60	19.76
1.5R: Outcrops of very fine sand and coarse silt	<10	279.03
	10 to 60	248.31
1.5NR	<10	290.01
	10 to 60	312.42
<u>Silt/clay Areas</u>		
2.1R: Silt/clay with crust	<10	87.95
	10 to 60	79.68
2.1NR	<10	83.03
	10 to 60	79.30
2.2R: Silt/clay with gravel	<10	145.39
	10 to 60	130.61
2.2NR	<10	161.32
	10 to 60	138.50
2.3R: Aggregated silt deposits	<10	18.56
	10 to 60	24.87
2.3NR	<10	27.44
	10 to 60	33.46
2.4R: Disturbed silt surfaces	<10	25.10
	10 to 60	24.40
2.4NR	<10	23.54
	10 to 60	26.02

Table 2 (ctd): Arsenic concentrations in airborne (PI-SWERL) samples. Surface unit 3.5 (bedrock) was not sampled.

Surface Unit Description	Particle Size (μm)	As ($\mu\text{g g}^{-1}$)
<u>USEPA Regional Screening Levels⁽¹⁾</u>		
Residential Soil		0.39
Groundwater Protection		0.0013
<u>Rock-covered Areas</u>		
3.1R: Desert pavements	<10	28.11
	10 to 60	26.46
3.1NR	<10	24.86
	10 to 60	22.34
3.2R: Rock-covered surfaces with silt/clay zones	<10	27.88
	10 to 60	21.85
3.2NR	<10	18.85
	10 to 60	16.13
3.3R: Rock-covered surfaces with sandy loam	<10	32.93
	10 to 60	25.84
3.3NR	<10	30.98
	10 to 60	70.64
3.4R: Rock-covered surfaces with encrusted sand	<10	44.03
	10 to 60	49.54
3.4NR	<10	41.74
	10 to 60	41.43
<u>Drainage Areas</u>		
4.1R: Gravelly drainages	<10	64.33
	10 to 60	70.59
4.1NR	<10	78.14
	10 to 60	70.24
4.2R: Gravel and sand drainages	<10	54.16
	10 to 60	45.35
4.2NR	<10	44.15
	10 to 60	41.27
4.3R: Gravel and silt/clay drainages	<10	65.13
	10 to 60	66.00
4.3NR	<10	94.09
	10 to 60	72.20
<u>Parking Lot Areas</u>		
North Parking Lot #1	<10	28.09
	10 to 60	20.03
North Parking Lot #2	<10	27.76
	10 to 60	23.99
South Parking Lot #1	<10	34.34
	10 to 60	19.25
South Parking Lot #2	<10	23.56
	10 to 60	17.10
Southeast Parking Lot #1	<10	45.24
	10 to 60	39.89
<u>Standard Samples</u>		
BRS1		21.08
BRS2		19.16
BRS3		20.33
BRS4		18.46
BRS5		18.64
Buffalo River Reference Material 8704		17

Notes:

(1) The Screening Levels (SLs) are developed using risk assessment guidance from the EPA Superfund program and are used for site "screening" and as initial cleanup goals, if applicable. The groundwater protection concentrations shown are soil concentrations considered to be protective of groundwater.

(2) R samples collected within ORV trails

(3) NR samples collected in undisturbed areas

Table 3: pH, electrical conductivity and soluble arsenic concentrations in airborne (PI-SWERL) dust extracts. Surface unit 3.5 (bedrock) was not sampled.

Surface Unit Description	pH	Electrical Conductivity (dS m⁻¹)	As (µg g⁻¹)
<u>Sand and Sand-Affected Areas</u>			
1.1R ⁽¹⁾ : Dunes with no vegetation	8.23	2.43	1.78
1.1NR ⁽²⁾	7.81	0.90	0.55
1.2R: Dunes with vegetation	7.83	0.76	4.36
1.2NR	8.18	0.18	2.23
1.3R: Disturbed sand surfaces	8.47	0.62	6.82
1.3NR	8.15	0.28	0.61
1.4R: Patchy layers of sand over silty/rocky subsoil	7.44	1.85	6.05
1.4NR	7.43	1.42	2.80
1.5R: Outcrops of very fine sand and coarse silt	7.86	2.87	8.04
1.5NR	7.55	2.31	4.13
<u>Silt/clay Areas</u>			
2.1R: Silt/clay with crust	7.50	1.70	8.28
2.1NR	8.05	0.35	5.88
2.2R: Silt/clay with gravel	7.86	2.15	9.24
2.2NR	7.84	2.11	10.59
2.3R: Aggregated silt deposits	7.74	1.78	5.02
2.3NR	7.83	2.19	1.49
2.4R: Disturbed silt surfaces	7.63	2.08	9.58
2.4-NR	7.76	1.46	2.17
<u>Rock-covered Areas</u>			
3.1R: Desert pavements	7.91	0.72	0.81
3.1NR	8.29	0.38	1.04
3.2R: Rock-covered surfaces with silt/clay zones	8.06	0.42	0.87
3.2NR	8.60	0.30	0.65
3.3R: Rock-covered surfaces with sandy loam	8.21	0.30	1.91
3.3NR	8.11	0.32	1.40
3.4R: Rock-covered surfaces with encrusted sand	8.13	0.07	2.20
3.4NR	6.58	0.06	0.42
<u>Drainage Areas</u>			
4.1R: Gravelly drainages	7.87	2.26	3.11
4.1NR	8.39	0.48	3.47
4.2R: Gravel and sand drainages	7.71	1.74	2.17
4.2NR	7.87	1.26	14.71
4.3R: Gravel and silt/clay drainages	8.07	0.40	3.93
4.3NR	8.56	0.12	9.15
<u>Parking Lot Areas</u>			
North Parking Lot #1	8.03	0.85	1.38
North Parking Lot #2	7.93	1.03	1.04
South Parking Lot #1	9.11	1.96	7.78
South Parking Lot #2	8.31	0.50	1.32
Southeast Parking Lot #1	8.28	0.44	5.57

Notes:

- (1) R samples collected within ORV trails
(2) NR samples collected in undisturbed areas
(3) NA = Not applicable

5. Discussion

5.1 Occurrence of arsenic at NDRA

The results indicate that arsenic is preferentially concentrated in the drainages that receive increased runoff and concentrate soluble arsenic (surface units 4.1 to 4.3), and/or in map units that contain increased clay content (surface units 2.1 to 2.4; and 4.3). The highest concentrations of As in *soil samples* occurred within the silt/clay areas (surface units 2.1 to 2.4), the drainages (surface units 4.1 to 4.3), and surface unit 1.5 (Table 1). The highest concentrations of As in *airborne sediment* (PI-SWERL samples) occurred in surface units 1.5, 2.1, 2.2 and all drainages (surface units 4.1 to 4.3). The highest concentrations of *soluble arsenic in airborne sediment* (PI-SWERL samples) occurred in two of the drainages (surface units 4.2 and 4.3), the silt/clay areas (2.1, 2.2, 2.4) and surface unit 1.5. For most of the airborne samples, the As concentrations were generally higher in the PM10 fraction than in the 10-60 μm fraction, and these fractions were significantly higher than the <2 mm bulk soil samples.

The high concentrations of As occurring in the drainage areas (surface units 4.1 to 4.3) combined with the water-soluble As results indicate that significant amounts of soluble arsenic is being dissolved and concentrated in the dry washes at NDRA during rainfall events. Much more detailed work is required to determine the specific mineral-As associations. However, studies in other regions have found that soluble arsenic minerals such as sodium arsenates occur in neutral to alkaline soils (McBride, 1994; Matera and LeHécho, 2001). Other studies have found arsenic to be either sorbed onto the surface of soluble calcite or gypsum; or present in their mineral structures due to isomorphic substitution (Roman-Ross et al., 2003; Di Benedetto et al., 2006; Fernández-Martínez et al., 2008). Additional mechanisms that can release As into solution include reductive dissolution of Fe-oxides and oxidative dissolution of sulfide minerals as well as redox cycling of As (Hering and Kneebone, 2002; Huerta-Diaz et al., 1998). Manganese may also play a role in controlling As mobility, as a result of redox reactions of manganese oxides with arsenite. More research is needed to identify the mineralogy of the soluble arsenic measured in this study (Table 3). However, the relatively high arsenic concentrations even in the coarse textured sandy drainages (unit 4.2) indicate significant re-mobilization of arsenic in these sediments.

The highest values of non-water-soluble arsenic in the PI-SWERL data are found in two units: 2.2 and 1.5. Interestingly both of these units have a distinct yellow color. Although XRD data (see Chapter 8) did not indicate any Fe-oxide minerals, the yellow color strongly suggests that one or more Fe-oxide-hydroxide substances may be present. Detection of well- to moderately well-crystalline Fe-oxide minerals by XRD analyses is generally possible when a given Fe-oxide mineral comprises 3 to 5% (w/w) of the sample

(Bigham et al., 2002). Identification of poorly crystalline Fe-oxide phases by XRD is more difficult, and amorphous Fe-oxides cannot be identified by XRD analyses. Therefore, the yellow color may result from Fe-oxide-hydroxide coatings on grains that were not abundant enough to be detected by XRD analyses, or from poorly crystalline or amorphous Fe-oxides. Because Fe-oxides have a high sorption affinity for trace elements (Bigham et al., 2002), including arsenic, this may explain the correlation between the yellow color and the high arsenic contents in these two units.

The increased As concentrations in the finer textured map units and in finer PI-SWERL fractions suggests retention of As on clay complexes or Fe-oxide-hydroxides and/or concentration of As within clay or other fine-grained mineral species. XRD analyses reveal that the mineralogical composition of the clay (<2 μm) and silt (2-20 μm) fractions of the soil samples at NDRA is dominated by smectite with lesser amounts of palygorskite, mica/illite, kaolinite, quartz, and calcite (see Chapter 8). Gypsum was also identified in several samples, although it should be noted that most of the gypsum present would have been removed during the distilled water rinses prior to fractionation and XRD analyses (see Chapter 8). Smectites are known to be major contributors to soil cation exchange capacity (CEC) and therefore, affect the retention of metals in the soil (Reid-Soukup and Ulery, 2002). Sorption of As onto the surface and isomorphic substitution within the structures of both calcite (Roman-Ross et al., 2003; Di Benedetto et al., 2006) and gypsum (Roman-Ross et al., 2003; Fernández-Martínez et al., 2008) have also been reported. Additionally, these fine-textured surface units (2.1 to 2.4; and 4.3) have decreased permeability that minimizes leaching of As during rainfall events.

Many other studies have shown that As is often preferentially concentrated in finer size fractions. Chen et al. (1999) reported that clay content and CEC were highly correlated with As concentrations in Florida surface soils. Van Pelt and Zobeck (2007) quantified the chemical constituents of fugitive dust in the Southern High Plains of Texas. These investigators also reported that the finer particles in the source soils contained higher concentrations of chemical constituents, including As. However, As concentrations in the source soils in Van Pelt and Zobeck's (2007) study were lower than those in the NDRA soils, ranging from 1.13 to 3.89 $\mu\text{g g}^{-1}$. Another possibility is that the As in the NDRA soil is associated with smectite minerals. Pascua et al. (2005) reported the occurrence of an As-rich smectite (1,500 to 4,000 ppm) in a geothermal field in Japan. These investigators found that minimal adsorption of As on smectite surfaces had occurred. Rather, the As was predominantly dissolved within the smectite or occurred within mineral occlusions. Additional studies are currently underway to determine the geological processes that lead to the concentration of As in these sediments.

In the Nellis Dunes Recreation Area there is not a clear relationship between As concentrations and location of disturbed (i.e., ORV trail) versus undisturbed surfaces. For the PM10 samples, As concentrations in 9 of the 16 ORV trail samples were higher (1.56 to 16.18 $\mu\text{g g}^{-1}$) than those measured in the associated undisturbed terrain samples, and approximately equal in one sample (Table 2). In the other six PM10 samples, the As

concentrations in the undisturbed terrain samples ranged from 3.25 to 28.96 $\mu\text{g g}^{-1}$ higher than those detected in the associated ORV trail samples. Arsenic concentrations in the 10-60 μm fraction were higher in 7 of the 16 ORV trail samples (2.03 to 8.11 $\mu\text{g g}^{-1}$) and approximately equal in three samples as compared to the associated undisturbed terrain samples (Table 2). The As concentrations in the other six ORV trail samples were from 1.62 to 64.11 $\mu\text{g g}^{-1}$ lower than those reported in the corresponding undisturbed terrain samples.

5.2 Regional and national distribution of arsenic in soils

Naturally occurring background concentrations of arsenic vary regionally because of a combination of climatic, geologic, and anthropogenic factors. Sources of As in the environment include weathering of As-bearing rocks and minerals, volcanic eruptions, fly ash from coal burning plants, smelter fumes released during the treatment of As-containing metallic ores, mining wastes, and application of arsenical pesticides, herbicides and corrosion inhibitors. Because the only anthropogenic process occurring at NDRA is ORV activity, it is believed that the arsenic at NDRA is naturally occurring as a result of regional geologic processes.

The concentrations of As in some of the soil samples at NDRA are substantially higher (3.49 to 83.02 ppm) than in soils elsewhere in the United States, where the average ranges from 3.6 to 8.8 ppm; and throughout the world where averages range from 2.2 to 25 ppm (McBride, 1994). In a 1975 study of 21 soil samples collected in the western United States, As concentrations ranged from non-detectable to 97 ppm with an average concentration of 6.1 ppm (Connor and Shacklette, 1975). In another study, As analyses were performed on 50 soils collected throughout California. Arsenic concentrations in these soils ranged from 0.6 to 11 ppm, with an average concentration of 3.5 ppm (Bradford et al., 1996). Reheis et al. (2009) report median As concentrations of 10 ppm in surface soil samples in southern Nevada and California. However, five surface soil samples in that study contained As concentrations ranging from approximately 30 to 50 ppm.

Arsenic concentration data for the entire United States is also available from a soil inventory prepared by the United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS, 2010). This database includes information on As concentrations in more than 2,800 soil samples collected at over 480 different locations in the United States. Using this data, we constructed a figure showing the reported soil As concentrations (Fig. 2). Arsenic concentrations in the USDA-NRCS database are nearly always less than 20 ppm, and rarely above 30 ppm. Comparing this data shows that As concentrations for most surface units at NDRA are comparable with those measured elsewhere in the United States (Table 1). The exceptions are the drainage units (4.1, 4.2, and 4.3) and units 1.5 and 2.2, which have anomalously high As concentrations.

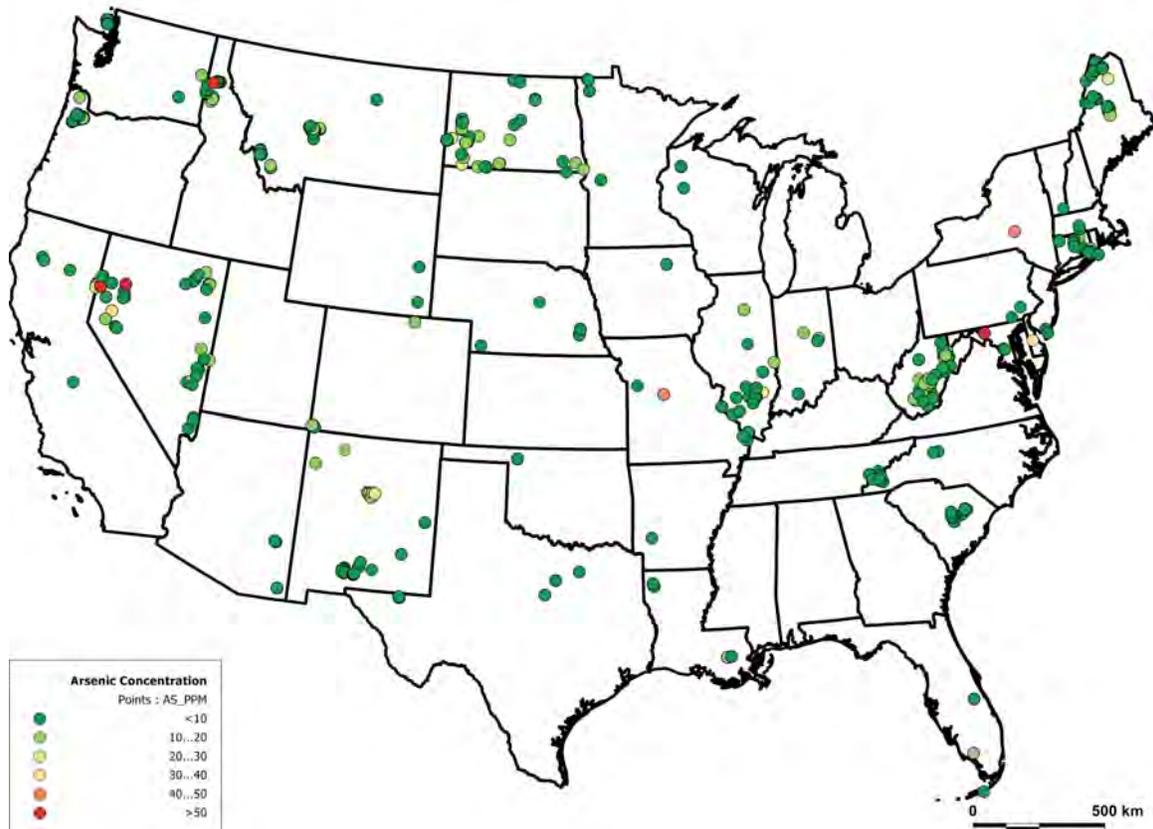


Fig. 2: Arsenic concentration in soil samples from the United States.
Source: UDSA-NRCS, 2010.

The reported As concentrations in soils for NDRA units 1.5 and 2.2 are among the highest documented in the United States to date. Breit et al. (2009) reported As concentrations in the water soluble soil fraction at Franklin Lake Playa (approximately 100 km southwest of NDRA) over 400 ppm, but these values were measured at a depth of more than 50 cm below the playa surface. Arsenic concentrations were much lower closer to the playa surface, <100 ppm at a depth of 20 cm and <50 ppm in the uppermost 10 cm. Reynolds et al. (2008) and Goldstein et al. (2008) reported water-soluble salts on the ground surface in Ash Meadows and Carson Slough, immediately north of Franklin Playa, had As concentrations as high as 600 ppm. The Reynolds et al. (2008) and Goldstein et al. (2008) studies are the only studies performed on non-mining sites in the western United States that we are aware of with reported As concentrations higher than those of NDRA unit 2.2.

5.3 Arsenic in dust

Few studies have analyzed As in airborne dust, and none have reported values as high as found in the current Nellis Dunes study. Reheis et al. (2002) studied the contributions of different local sources to dust in the southwestern United States by comparing elemental analyses of samples collected from dust traps to analyses of samples from potential source sediments, such as alluvial and playa deposits. The average concentration of As in the <50 μm fraction of dust samples ranged from 5 to 25 ppm. The results of the Reheis et al. (2002) study also showed that all dust samples were enriched in As relative to source samples, and that dusts in the Owens Valley have higher concentrations of As than dust samples from other areas. The highest concentrations of As occurred in Owens Valley alluvium and lake-marginal deposits away from the dry bed of Owens Lake. The average concentration of As in the <50 μm fraction from the Owens Valley lake bed samples was reported to be 40 ppm and 45 ppm in dust from elsewhere in Owens Valley (Reheis et al., 2002). More recently, Reheis et al. (2009) conducted a compositional study of modern dust and surface sediments in southern Nevada and California. These investigators reported median As concentrations of 20 ppm in airborne dust (collected at a height of 2 m above the surface) and 10 ppm in surface soil samples. One outlier airborne dust sample had an As concentration of 50 ppm.

5.4 Arsenic hazards to health

Exposure to arsenic has been strongly linked to heart disease, hypertension, peripheral vascular disease, diabetes, immune suppression, acute respiratory infections, intellectual impairment in children, and skin, lung, prostate, bladder, kidney and other cancers (Chen et al., 1992; Abernathy et al., 1999; Järup, 2003; Tseng et al., 2003; Smith et al., 2006; von Ehrenstein et al., 2006; Kozul et al., 2009). Additionally, arsenic has been found to be uniquely harmful to lung tissue by inhibiting wound repair and altering genes associated with immune functions in lung tissue (Olsen et al., 2008; Kozul et al., 2009a; Kozul et al., 2009b).

Because of this, the reported concentrations of As in the digested soil and PI-SWERL samples were initially compared with the USEPA Region 3, 6, and 9 screening levels (SLs) for chemical contaminants in residential soils and soil concentrations considered to be protective of groundwater resources (USEPA, 2010). The SLs are developed using risk assessment guidance from the EPA Superfund Program and are used for site “screening” and as initial cleanup goals, if applicable. The risk-based SLs are considered by the EPA to be protective for humans (including sensitive groups) over a lifetime. However, it should be noted that the SLs may not be applicable at a particular site and they do not address non-human health endpoints, including ecological impacts. The As concentrations in all of the NDRA samples analyzed exceed the EPA’s SL of 0.39 $\mu\text{g g}^{-1}$ for As in residential soil by one to three orders of magnitude (Table 1).

The reported concentrations of As in all of the samples exceed the EPA SLs considered to be protective of groundwater. Although the reported As concentrations exceed the EPA SLs, the potential risk to groundwater resources from leaching of As is considered to be minimal in the Nellis Dunes area. This is because groundwater in the Nellis Dunes area is deep (>30 m below ground surface), and the arid climate minimizes leaching. However, the high soluble concentrations of As are of concern because of the potential for downstream contamination from runoff. Lake Mead, a major drinking water source for Las Vegas, is located hydrogeologically downgradient of the NDRA.

The most important potential health hazard in this area is human exposure to As through inhalation of dust. In order to better understand potential risks of As in dust emissions we calculated PM10 emission rates for As resulting from natural wind erosion in NDRA for each surface unit. We multiplied the emission rates for total PM10 dust (published in the study by Goossens and Buck, 2010) with the As content of the PM10 PI-SWERL samples. PI-SWERL samples are used in the calculation because they represent the sediment fractions prone to emission during wind erosion. For unit 3.5, where no PI-SWERL samples could be taken, we used a similar As content as for unit 3.1 because the rock cover is almost 100% for these units and because the dust in these units is not affected by the underlying geologic deposits but is entirely created by settling airborne background dust. Note that because water was necessary to fractionate the samples to <10 μm , the water-soluble As concentrations are not included in these calculations. Therefore the As emission rates presented here are minimum values. The As emission rates ranged from a low of $9.74 \times 10^{-18} \text{ g cm}^{-2} \text{ s}^{-1}$ in surface unit 3.5 (bedrock and/or outcropping petrocalcic horizons) to a maximum of $3.67 \times 10^{-14} \text{ g cm}^{-2} \text{ s}^{-1}$ in surface unit 1.5 (outcrops of very fine sand and coarse silt). Emission rates for As were also high in the other units containing sand (1.1, 1.2, 1.3, 1.4 and 3.4; see Fig. 3).

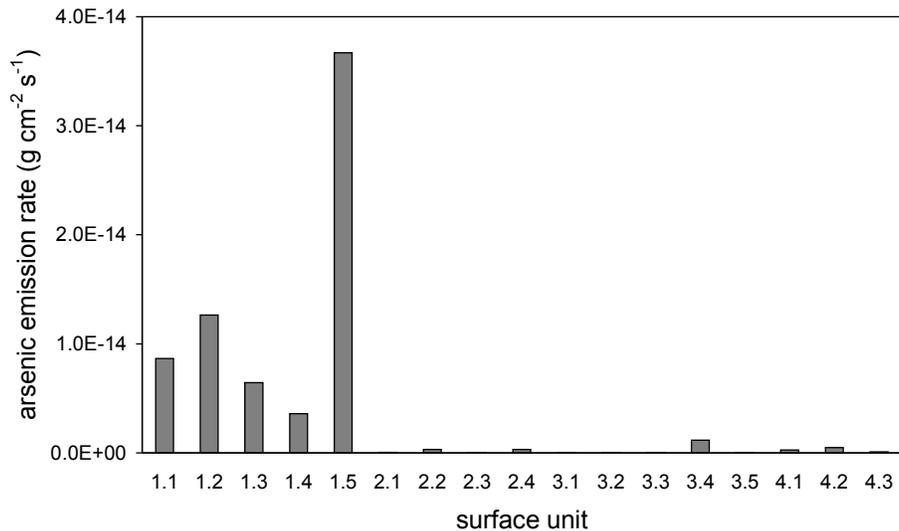


Fig. 3: Emission rate for arsenic during wind erosion. Data are for the fraction <10 μm (PM10).

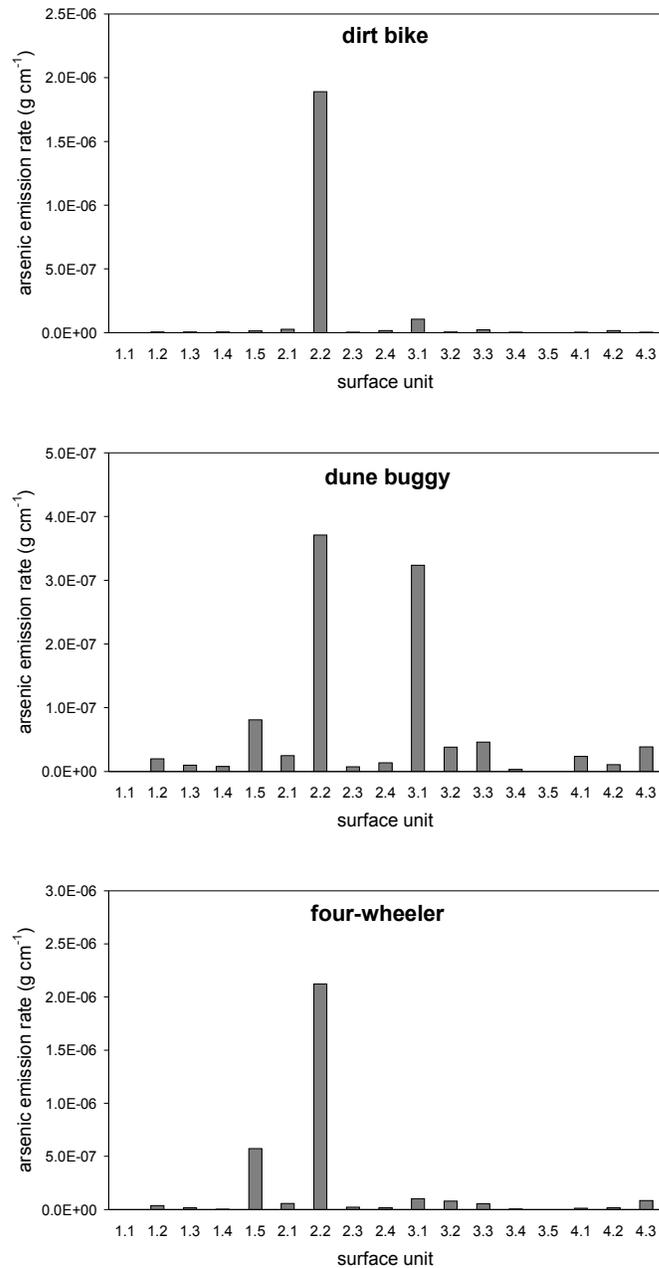


Fig. 4: Emission rate for arsenic during ORV activity: (a) Dirt bike; (b) Dune buggy; (c) Four-wheeler. Data are for the fraction $<10 \mu\text{m}$ (PM10) and for an average driving speed of 30 km h^{-1} .

Similarly, we calculated PM10 emission rates for As resulting from ORV activities (Figs. 4a,b,c). These rates were calculated by multiplying the ORV emission rates for total PM10 dust (available from the study by Goossens and Buck, 2009) with the As concentration in the PM10 PI-SWERL samples. Again, water-soluble As concentrations

are not included in these calculations and therefore the As emission rates are minimum values. The emission rates for each ORV activity were highest in surface units 2.2 (silt/clay with gravel) and 3.1 (desert pavements) and lowest in surface unit 3.4 (rock-covered surfaces with encrusted sand). High emission rates were also measured in surface unit 1.5 (mixture of fine sand and coarse silt) for the four-wheeler. The As emission rates ranged from $2.57 \times 10^{-9} \text{ g cm}^{-1}$ to $1.89 \times 10^{-6} \text{ g cm}^{-1}$ for dirt bikes, $3.08 \times 10^{-9} \text{ g cm}^{-1}$ to $3.71 \times 10^{-7} \text{ g cm}^{-1}$ for dune buggies, and $1.58 \times 10^{-9} \text{ g cm}^{-1}$ to $2.12 \times 10^{-6} \text{ g cm}^{-1}$ for four-wheelers. These rates are calculated for a driving speed of 30 km hr^{-1} , which is a conservative, but representative average for the NDRA. At higher driving speeds, emission rates are considerably higher. For example, for an average vehicle (average of a dirt bike, dune buggy, and four-wheeler), the emission rate nearly doubles at 40 km hr^{-1} (average rate of increase for all units together: 1.89 times), and at 50 km hr^{-1} more than triples (average rate of increase for all units together: 3.27 times).

The potential health effects of the dust generated during ORV use at the NDRA are not known because emissions vary greatly depending on what type of vehicle is used, how intensely an area is driven, and whether riders drive closely behind one another. Information regarding the exact number of drivers, the length of each drive and the specific routes followed is also unknown (Goossens and Buck, 2009). It is also important to note that the grain size distribution of the PI-SWERL released dust does not necessarily correspond to that of ambient dust. The PI-SWERL dust is locally eroded dust whereas ambient dust also contains particles that were eroded elsewhere and are in transport. Archived ambient dust samples that were previously collected at NDRA using BSNE samplers will be analyzed in the future to evaluate whether As concentrations are similar to those in the PI-SWERL samples. In order to determine the actual exposures, monitoring of personal dust exposure must be performed on ORV users under different driving conditions, and on other visitors at the site.

6. Conclusions

The concentrations of As in soil samples at NDRA are substantially higher (3.49 to 83.02 ppm) than in soils elsewhere in the United States (average ranges from 3.6 to 8.8 ppm); and throughout the world (averages range from 2.2 to 25 ppm) (McBride, 1994). There is no evidence to suggest that the As at NDRA is derived from anything other than natural geological processes. At NDRA, greater As concentrations are associated with finer grain-size fractions and areas that receive run-off. The As is likely being held on clay or Fe-oxide-hydroxide complexes, concentrated within soluble sodium and calcium arsenates, and/or other arsenic containing minerals including calcite and gypsum. High values of soluble As in some surface units explain the increased As concentration within dry arroyos. There is not a clear relationship between As concentrations and disturbed (i.e., ORV trails) versus undisturbed surfaces. It is hoped that future work will identify the mineral phases containing the As and further explain the geological history of As enrichment at the Nellis Dunes site.

Few studies have documented the As content in dust samples, and none have reported values as high as those reported in this study. Arsenic concentrations in emitted dust are much higher than As concentrations in the associated soil. For emitted PM₁₀, the concentrations are, on average for all surface units, 4.5 times higher than in the soil. However, substantial differences occur between units. For sand units, the concentrations were 5 times or more greater for units 1.3, 1.4, and 1.5, and more than 10 times greater for units 1.1 and 1.2. Units rich in silt and poor in sand had the lowest enrichment rates of As compared to the associated soils (<2.5 times greater). Units dominated by rocks exhibited intermediate values. For coarser dust fractions (10-60 μm), the numbers are comparable, although the relationship with the type of unit is more subtle.

The highest concentrations of As measured in this study occurred in the samples from units 1.5 and 2.2. Arsenic concentrations in soil samples from these units were 46 and 83 ppm, respectively. Concentrations of As in PM₁₀ emitted dust from these units were 290 and 161 ppm, respectively, and in the emitted 10-60 μm dust fraction, 312 and 139 ppm. Note that the actual As concentrations in the PM₁₀ and 10-60 μm dust fractions are even higher because these values do not include the water-soluble As contents. These values are among the highest measured in the United States to date. These units are of special concern because unit 1.5 is highly susceptible to wind erosion and unit 2.2 is the unit with the highest dust production when subject to ORV driving.

Concentrations in all of the samples analyzed exceed the EPA's screening level (SL) of 0.39 $\mu\text{g g}^{-1}$ for As in residential soil by one to three orders of magnitude. The reported concentrations of As in all of the samples also exceed the EPA SLs considered to be protective of groundwater. Although the reported As concentrations exceed the EPA SLs, the potential risk to groundwater resources from leaching of As is considered to be minimal. This is because of the arid climate and groundwater in the Nellis Dunes area is deep (>30 m below ground surface). However, the high soluble concentrations of As are of potential concern because of the possible downstream contamination from runoff. Lake Mead, the source of drinking water for Las Vegas, is located hydrogeologically downgradient of the site.

The most important potential pathway for As exposure to humans at NDRA is through inhalation of dust. Arsenic has been strongly linked to a long list of diseases. Therefore, dust containing As will likely have increased health effects beyond those caused by PM₁₀ size fractions alone. However, the potential for negative health effects to ORV operators, site visitors, and others exposed to emissions from NDRA is currently unknown because of several different factors. In order to accurately evaluate the potential health effects, monitoring of personal dust exposure must be performed on ORV users and other site visitors. The actual concentration of As in the air must also be quantified, since existing standards for As exposure in the workplace are based on the concentrations in air. Currently, there are no standards in the United States for As in recreational settings. There is also no information available regarding potential As concentrations in dust generated at the NDRA after it is transported downwind to Las Vegas and

surrounding urban areas. Finally, toxicological analysis of the impact NDRA arsenic emissions exert on the human body, and a full risk analysis of all 17 surface units occurring in the NDRA, are required to define the health risk the arsenic at NDRA exposes to the population in Clark County

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