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# Preliminary Evaluation of Metal Contamination of Soils from the Gulf War Activities

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Oil burning in Kuwait, atmospheric fallout of particulates from the use of explosives in the Gulf War, and war-related ground activities created serious air pollution problems in the neighboring countries. A large area of Saudi Arabia might have been adversely affected from these activities. In an effort to assess the impact of these problems on air quality, the Research Institute of King Fahd University of Petroleum and Minerals (KFUPM/RI) initiated an air monitoring program. As a part of the program, soil samples were collected by the Meteorology and Environment Protection Administration (MEPA) and were analyzed for toxic metals. This paper discusses analytical results of these soil samples. It is realized that the paper might have scientific and statistical limitations, but the data reported would be of interest to many environmentalists who care to know the impact of the Gulf War on the terrestrial environment in this region.

## MATERIALS AND METHODS

Immediately after the cessation of hostalities in Kuwait, a special task team was established under MEPA to assess environmental problems in the Hafr Al Batin area. During a field reconnaissance trip to the area, the team collected soil samples from 10 locations using a hand auger. Approximate locations of all these samples are shown in Figure 1. Soil samples, about one kg each, were collected from 00-05 cm and from 15-25 cm depth from 3-5 sites at the same location and composited. The composite samples were stored in plastic bags and transported to KFUPM/RI. There was a rain storm around the Naariyah area a few days before the sampling and the team also observed a sand storm in Hafr Al Batin during this sampling trip.

All the soil samples were air dried, sieved through a 35-mm sieve, mixed thoroughly and stored in plastic containers. Duplicate samples of two grams each were taken in 150 mL digestion tubes from each sample. Ten mL of aqua regia [three parts of conc hydrochloric acid and one part conc nitric acid) to break the solid matrix and 3 mL of conc perchloric acid to oxidize organic matter were added to each tube. The tubes were heated first at 60°C for one hour and then at 120°C for three hours. On cooling, the content of each tube was filtered through Whatman # 44 filter paper. The tubes and filter papers were washed thoroughly

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with distilled water. The solids left over on the filter paper were discarded and the final volume of the filtrate was increased to 50 mL using glass-distilled water. Concentrations of barium, cadmium, cobalt, copper, chromium, molybdenum, nickel, lead, titanium, vanadium, tungsten, and zinc were determined in the filtrates using an inductively coupled argon plasma analyzer (ICAP).

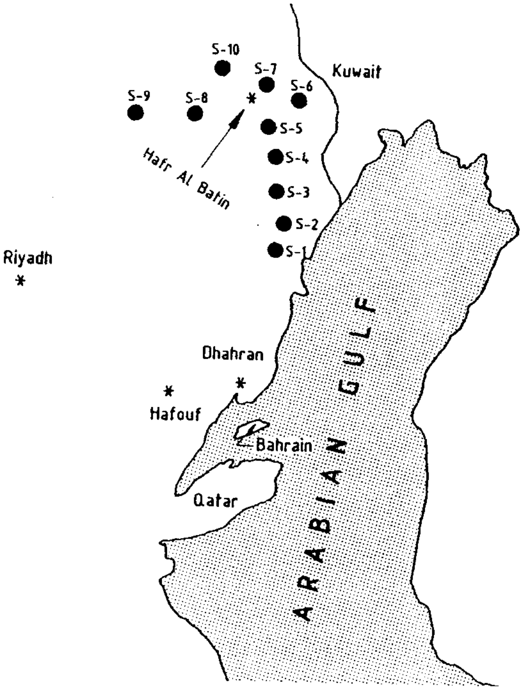

Figure 1. Map showing soil sampling locations. The locations are our best approximation

## RESULTS AND DISCUSSION

Concentrations of barium, cadmium, cobalt, chromium, copper, lead, nickel, molybdenum, vanadium, titanium, zinc and tungsten were determined in the soil samples and are summarized in Table 1.

Barium concentrations ranged between 7 and 99 mg/kg soil. The maximum barium concentrations were found in S-4 and S-5 soil samples. In general, barium was higher in the surface samples (00-05 cm) than those collected from 15-25 cm depth at the same location. The maximum cadmium concentration was found in the surface S-6 soil sample - almost three times higher than in the samples taken from 15-25 cm depth. Soil sample S-6 was collected 60 km from the Kuwaiti border and is the closet point to Kuwait in this study. The other soil samples with relatively high cadmium concentrations were S-7 and S-8. In general, cadmium concentrations in the surface soil samples were higher than those collected from 15-25 cm depth.

Table 1. Mean metal concentrations (mg/kg soil) of three replicates of soil samples collected from Hafr Al Batin Area.

| SAMPLE | Depth(cm) | Barium | Cadmium | Cobalt | Chromium |
|---|---|---|---|---|---|
| S-1A | 00-05 | 29.25 | 4.00 | 3.50 | 12.50 |
| S-1B | 15-25 | 19.50 | 3.50 | 3.00 | 11.25 |
| S-2A | 00-05 | 21.75 | 3.25 | 3.50 | 18.75 |
| S-2B | 15-25 | 20.00 | 3.75 | 3.50 | 15.50 |
| S-3A | 00-05 | 52.50 | 3.50 | 3.00 | 12.00 |
| S-3B | 15-25 | 47.50 | 6.25 | 6.75 | 28.25 |
| S-4A | 00-05 | 99.25 | 6.50 | 6.50 | 26.50 |
| S-4B | 15-25 | 38.25 | 5.50 | 5.50 | 73.50 |
| S-5A | 00-05 | 90.75 | 6.25 | 6.50 | 28.75 |
| S-5B | 15-25 | 18.50 | 3.25 | 7.00 | 33.75 |
| S-6A | 00-05 | 48.75 | 11.75 | 16.00 | 79.75 |
| S-6B | 15-25 | 32.00 | 4.00 | 6.50 | 28.75 |
| S-7A | 00-05 | 37.75 | 8.25 | 7.25 | 30.75 |
| S-7B | 15-25 | 7.25 | 6.50 | 7.00 | 26.25 |
| S-8A | 00-05 | 47.25 | 9.00 | 11.00 | 45.00 |
| S-8B | 15-25 | 30.50 | 7.75 | 7.00 | 27.25 |
| S-9A | 00-05 | 17.00 | 1.75 | <1.00 | 0.55 |
| S-9B | 15-25 | 15.25 | 1.50 | <1.00 | <1.00 |
| S-10A | 00-05 | 38.75 | 9.25 | 12.50 | 47.50 |
| S-10B | 15-25 | 25.50 | 6.75 | 7.25 | 28.75 |

| SAMPLE | Depth(cm) | Copper | Molybdenum | Nickel | Lead |
|---|---|---|---|---|---|
| S-1A | 00-05 | 5.25 | 6.00 | 23.00 | 9.25 |
| S-1B | 15-25 | 3.00 | 5.25 | 20.25 | 5.25 |
| S-2A | 00-05 | 1.75 | 4.75 | 20.00 | 6.75 |
| S-2B | 15-25 | 2.25 | 5.50 | 20.75 | 5.00 |
| S-3A | 00-05 | 2.50 | 5.50 | 15.00 | 7.00 |
| S-3B | 15-25 | 4.75 | 11.25 | 31.00 | 19.75 |
| S-4A | 00-05 | 5.50 | 11.00 | 31.00 | 20.75 |
| S-4B | 15-25 | 3.75 | 11.00 | 17.75 | 27.00 |
| S-5A | 00-05 | 4.75 | 8.50 | 30.25 | 22.25 |
| S-5B | 15-25 | 3.00 | 8.50 | 20.50 | 33.00 |
| S-6A | 00-05 | 2.50 | 14.00 | 74.00 | 52.00 |
| S-6B | 15-25 | 3.75 | 9.75 | 21.25 | 39.75 |
| S-7A | 00-05 | 2.75 | 10.00 | 26.25 | 25.75 |
| S-7B | 15-25 | 3.00 | 9.00 | 24.25 | 17.00 |
| S-8A | 00-05 | 7.00 | 14.75 | 43.25 | 34.75 |
| S-8B | 15-25 | 4.25 | 9.50 | 24.00 | 22.00 |
| S-9A | 00-05 | 1.00 | 2.00 | 9.50 | <1.00 |
| S-9B | 15-25 | 1.00 | 1.75 | 7.50 | <1.00 |
| S-10A | 00-05 | 9.00 | 14.50 | 49.00 | 47.50 |
| S-10B | 15-25 | 3.75 | 8.25 | 25.75 | 27.50 |

| SAMPLE | Depth(cm) | Titanium | Vanadium | Zinc | Tungsten |
|---|---|---|---|---|---|
| S-1A | 00-05 | 212.50 | 14.75 | 12.00 | 40.00 |
| S-1B | 15-25 | 225.00 | 14.50 | 7.75 | 35.00 |

Table 1. Contd.

| SAMPLE | Depth(cm) | Titanium | Vanadium | Zinc | Tungsten |
|---|---|---|---|---|---|
| S-2A | 00-05 | 195.00 | 14.00 | 8.75 | 36.50 |
| S-2B | 15-25 | 328.00 | 17.75 | 7.00 | 37.50 |
| S-3A | 00-05 | 247.50 | 14.00 | 6.50 | 36.00 |
| S-3B | 15-25 | 290.00 | 23.50 | 11.75 | 73.25 |
| S-4A | 00-05 | 309.50 | 34.75 | 12.75 | 73.75 |
| S-4B | 15-25 | 100.00 | 24.50 | 8.00 | 76.75 |
| S-5A | 00-05 | 500.00 | 27.50 | 13.50 | 66.25 |
| S-5B | 15-25 | 190.00 | 25.50 | 7.50 | 75.75 |
| S-6A | 00-05 | 900.00 | 59.00 | 23.50 | 126.50 |
| S-6B | 15-25 | 170.00 | 31.75 | 7.50 | 78.00 |
| S-7A | 00-05 | 470.00 | 32.25 | 16.50 | 69.50 |
| S-7B | 15-25 | 341.25 | 26.00 | 12.75 | 60.25 |
| S-8A | 00-05 | 380.00 | 43.75 | 19.75 | 101.50 |
| S-8B | 15-25 | 327.25 | 29.50 | 15.00 | 65.25 |
| S-9A | 00-05 | 100.00 | 3.50 | 5.50 | 6.25 |
| S-9B | 15-25 | 80.00 | 2.00 | 4.50 | 3.25 |
| S-10A | 00-05 | 372.50 | 41.00 | 23.25 | 115.50 |
| S-10B | 15-25 | 256.25 | 28.50 | 15.00 | 69.50 |

Cobalt concentrations in soil samples varied from below the detection limits of ICAP and 16.00 mg/kg. Like cadmium, the maximum cobalt concentration was found in the surface soil sample collected from the S-6 location. Concentrations of chromium varied from less than the detection limits of ICAP in the 15-25 cm depth sample from location S-9 and 79.75 mg/kg in the surface sample collected from S-6. In general, chromium concentrations in the surface soil samples were higher than in those collected from 15-25 cm depth. Unlike cadmium, cobalt and chromium, copper concentrations in the soil varied in a relatively narrow range, i.e., from 1.0 to 9.0 mg/kg. The distribution of copper exhibited no definite trend.

The maximum concentration of molybdenum was found in the surface soil sample collected from S-8 location. In general, molybdenum concentrations were higher in the surface samples than those collected from 15-25 cm. The maximum lead concentration (52 mg/kg) was found in the surface soil sample collected from location S-6. Sampling locations S-3 through S-8 and S-10 contained substantiality higher concentrations of lead, especially in the surface samples, than the other locations. Samples collected from 15-25 cm depth at locations S-1 through S-3 contained higher titanium concentrations than surface soil samples. However, at other locations, this trend was reversed.

Nickel varied between 7.50 (15-25 cm soil sample from S-9) and 74 mg/kg in the surface samples from location S-6. In general, lower nickel concentrations were found in samples collected from 15-25 cm than those in the surface samples. Except for S-1 to S-3, all the surface samples contained relatively higher vanadium concentrations than samples collected from 15-25 cm depth at the same location. The maximum concentration was found in the samples collected from the closet sampling location (S-6) to Kuwait. Soil samples from S-9, the farthest sampling point, contained the lowest vanadium concentrations. Kuwaiti crude oil contains about 10 and 30 mg/kg of nickel and vanadium, respectively [HPI Consultants Inc. 1987; KFUPM/RI, 1991]. In view of the large quantities of oil being burned in Kuwait, an appreciable concentration of these elements should be expected in the atmospheric fallout from Kuwait. In addition, these elements might have been extensively used in weaponries used in the Gulf War. Because of the presence of contamination sources in Kuwait, elevated concentrations of nickel and vanadium in the surface soil were expected in the Hafr Al Batin area.

Zinc concentrations varied from 4.5 to 23.5 mg/kg soil. Relatively higher concentrations of zinc were found in samples collected from S-4 through S-8 and S-10. In general, surface soil samples contained higher zinc concentrations than the soil samples collected from 15-25 cm depth. Tungsten is commonly used in steel alloys. The maximum and minimum tungsten concentrations were found in the surface soil sample collected from location S-6 (126.5 mg/kg) and soil sample from S-9 taken from 15-25 cm depth (3.25 mg/kg), respectively.

The highest concentrations of cadmium, cobalt, chromium, lead, nickel, titanium, vanadium and tungsten were found in the surface samples from location S-6 - a location nearest to the Saudi/Kuwaiti border. The lowest concentrations of these metals were found in the soil samples collected from the farthest sampling location (S-9) (Figure 1). These observations suggest that metal concentrations, at least in the surface soil, might be a function of distance from the Saudi/Kuwaiti border. This will particularly be true if the metal contamination of surface soil was related to the atmospheric fallout from Kuwaiti oil fires and other activities associated with the Gulf War.

To evaluate metal-distance relationship, sampling locations S-6, S-7, S-10, S-8 and S-9 which are almost in a line going away from the Saudi/Kuwaiti border (Figure 1), were considered. Only sampling location S-7 was excluded because of a probable disturbance of the surface soil due to intensive troop movements in this area. An approximate distance from the Saudi/Kuwaiti border was estimated for each of these sampling location.

Concentrations of cadmium, chromium, cobalt, nickel, lead, tungsten, vanadium and titanium, as a function of the approximate distance from the Saudi/Kuwaiti border, are plotted on Figure 2. The highest concentrations of all these metals were found in the soil samples collected 60 km from the Saudi/Kuwaiti border. Concentrations of these metals decreased as the distance from the Saudi/Kuwaiti increased. In general, a similar trend was followed by metal concentrations in the samples collected from 15-25 cm layer. The lowest concentrations of the above metals were found in the samples collected 300 km away from the Saudi/Kuwaiti border. The difference between metal concentrations in soil samples from the surface and those collected from 15-25 cm depth narrowed with distance from the border. These observations also suggest that the Gulf War activities were probably responsible for soil contamination in the study area. It should be mentioned here that during the Gulf War, there were about three relatively heavy rains in the area. As a result, it seems, that appreciable quantities of metals were probably washed to the lower soil depths. Because of this, metal concentrations in soil samples collected from 15-25 cm also showed a distance dependency.

In general, analytical results suggest that the Gulf War activities may have been responsible for the metal contamination of soils in the Hafr Al Batin area. Atmospheric fallout of explosives used in Kuwait and Kuwaiti oil fires could be the most important source of metal contamination in the study area. It was not

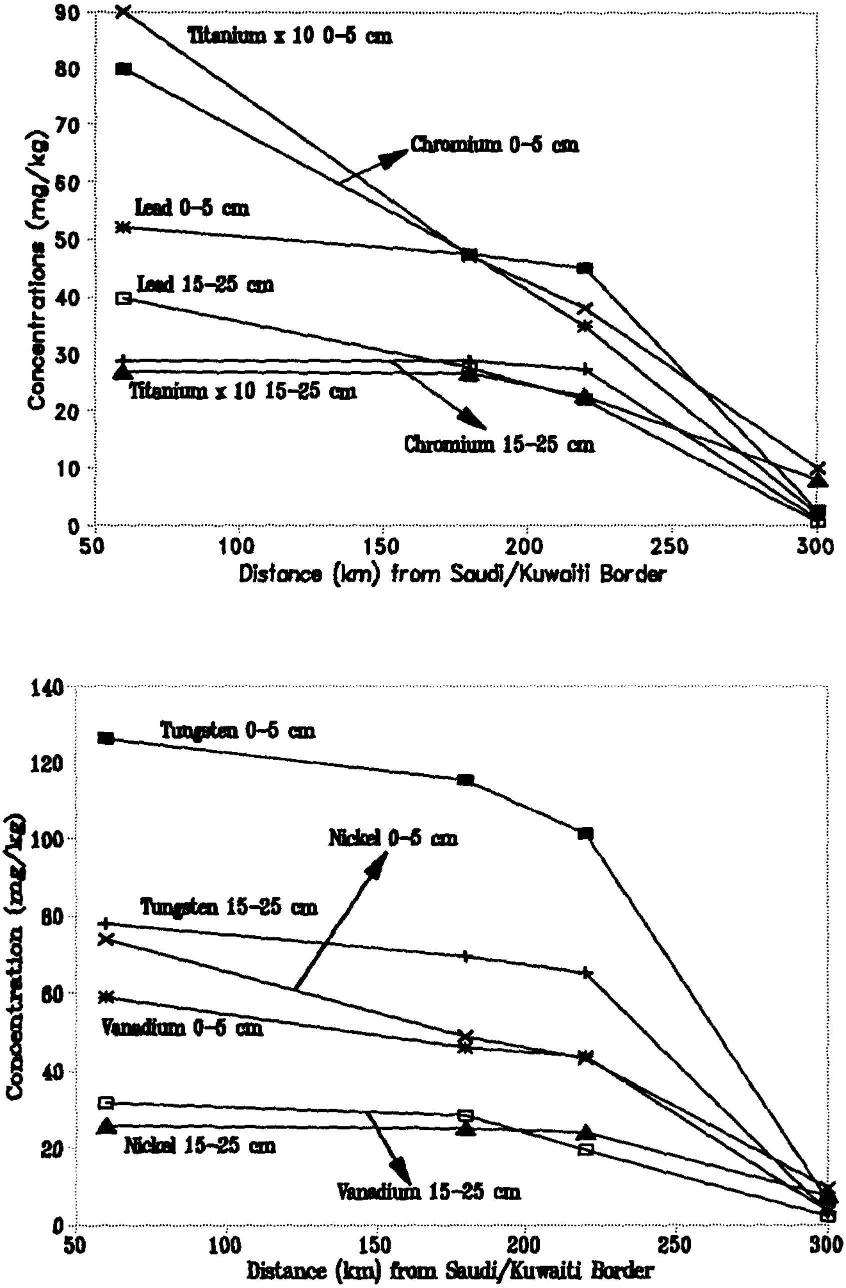

Figure 2. Metal concentrations as a function of distance from the Saudi/Kuwaiti border

possible to collect information on the quantities of explosives used and metal concentrations in different explosives. Hazards of metal contamination from the use of explosives, therefore, could not be quantitatively assesed.

As stated above, Kuwaiti oil fires are considered to be one of the major sources of metal contamination. No information was available on the total metal fluxes of these fires; therefore, concentrations of trace metals were determined in Kuwaiti crude oil that recently became available to our laboratory. These data were used to calculate approximate metal inputs of Kuwaiti oil fires to the ambient atmosphere. The results of these calculations are given in Table 2. It is obvious that Kuwaiti oil fires have emitted appreciable amounts of toxic metals, especially vanadium, nickel, and aluminum to the ambient atmosphere. Arsenic was also detected qualitatively in the oil samples.

Table 2. Approximate amount of metals emitted by the damaged oil wells in Kuwait (February to October, 1991)

| Metals | Amount (Tons) | Metals | Amount (Tons) |
|---|---|---|---|
| Aluminum | 819 | Cadmium | 25 |
| Cobalt | 18 | Chromium | 69 |
| Copper | 51 | Iron | 667 |
| Manganese | 18 | Molybdenum | 112 |
| Nickel | 1861 | Lead | 102 |
| Vanadium | 6450 | Zinc | 386 |

* One billion barrels of Kuwaiti crude oil is assumed to have been emitted by the damaged oil wells

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