THE IMPACTS OF OIL LAKES ON THE FRESH GROUNDWATER LENSES IN KUWAIT

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ABSTRACT

Kuwait is an arid country marked by scarce rainfall, high temperatures and evaporation rates, and lack of perennial surface waters. The only natural water resources of Kuwait is groundwater which is in either brackish or saline except in two locations. At Raudhalain and Umm Al-Aish areas the groundwater exist as fresh lenses due to high infiltration rate of the sandy Dibdibba Formation, which is the main strata at these areas. The local recharge occurs when the rainfall replenishes the water levels of the groundwater lenses depending on the conditions of the precipitation. However, the Gulf War in the year 1991 created a major environmental catastrophe unparalleled in the history of mankind. One of the major consequences of the Gulf War was setting alight several oil wells. The integrity of the fresh groundwater lenses at Raudhatain and Umm Al-Aish was threatened as a result of the heavily polluted ground surface due to this catastrophe. This study is a part of a preliminary study, which was undertaken in 1992-93 to establish the likelihood and the extent of groundwater pollution after this catastrophe. The main objectives of the current work were to measure the concentrations of heavy metals like Vanadium, Nickel, Chromium, Lead, and Cadmium and Hydrocarbons to estimate the background levels of these contaminants in native groundwater at Raudhatain and Umm Al-Aish areas and to determine the impacts of hydrocarbon pollution on groundwater quality. The results indicate that the concentrations of the selected pollutants in the collected water samples from certain wells close to the contaminated areas at Umm Al-Aish exceed the international standers. The concentrations of the selected contaminants in the collected water samples from other wells, far from polluted area do not exceeds these international standards.

INTRODUCTION

The Gulf War in the year 1991 created a major environmental catastrophe unparalleled in the history of mankind. One of the major consequences of the Gulf War was setting alight several oil wells. As a result, out of a total of 943 oil wells, 613 oil wells were on fire spewing out smoke, 76 oil wells were damaged and discharging oil, 99 wells were damaged, but neither discharged smoke nor oil, and 155 wells remained intact.

The total oil burnt due to oil wells on fire was estimated about 240 x 10^6 m^3. The products of combustion were spread over an area of about 1722 km^2, representing about 10 % of the total area of Kuwait (Fig. 1). The total oil spilled as a result of the damaged wells was about 3.5 x 10^6 m^3. The spilled oil was collected in about 300 oil lakes, spread over an area of about 49 km^2. Out of these, 3.3 x 10^6 m^3 of oil was recovered and exported. The rest was left behind as it was not economical to collect them. The oil that was left behind was subjected to severe weathering over the past years.

The ground surface at Raudhatain and Umm Al-Aish areas, which contain the only fresh groundwater lenses in Kuwait, was heavily polluted. The integrity of the fresh groundwater lenses at Raudhatain and Umm Al-Aish was threatened as a result of the ground surface pollution. A preliminary study was undertaken in 1992 - 93

This study is a part of a preliminary study, which was undertaken in 1992-93 to establish the likelihood and the extent of groundwater pollution after this catastrophe (Al-Sulaimi et al., 1992 and Al-Sulaimi et al., 1993). The main objectives of the current work were to measure the concentrations of Vanadium, Nickel, Chromium, Lead, and Cadmium heavy metal, and Hydrocarbons to estimate the background levels of these contaminants in native groundwater at Raudhatain and Umm Al-Aish areas and to determine the impacts of hydrocarbon pollution on groundwater quality. However, according to the recommendations of the previous studies a large-scale investigation and monitoring program were curried out, which is still in going in order to protect the valuable fresh groundwater lenses at the study area.

SITE SELECTION

The following major factors influenced the selection of sites for the present study:

1. Areas with significant levels of pollution.
2. Boundaries of fresh and brackish groundwater bodies, as well as the location of existing MEW water well fields with respect to the proximity of the polluted areas.
3. Design of existing water wells, in general, and the position of well intake zone compared with water table levels at Raudhatain and Umm Al-Aish fields, in particular.
4. Operational status of water wells.
5. The source of contaminants, which includes infiltration from oil lakes and contaminated water used for fire fighting, products of combustion at ground surface and subsurface leakage of oil from damaged oil well casings.

In view of these factors, the Raudhatain and Umm Al-Aish water fields were selected to investigate the pollution, mostly from the direct infiltration of oil and contaminated water used for fire fighting (Fig. 1). The Wafra and Umm Gudair water well fields were selected to analyze pollution sources from subsurface leakage, if any, from damaged oil well casings. In addition, the Sulaibiyah water well field, which is far from any known source of pollution, was selected to develop a database of naturally occurring heavy metals in native groundwater.

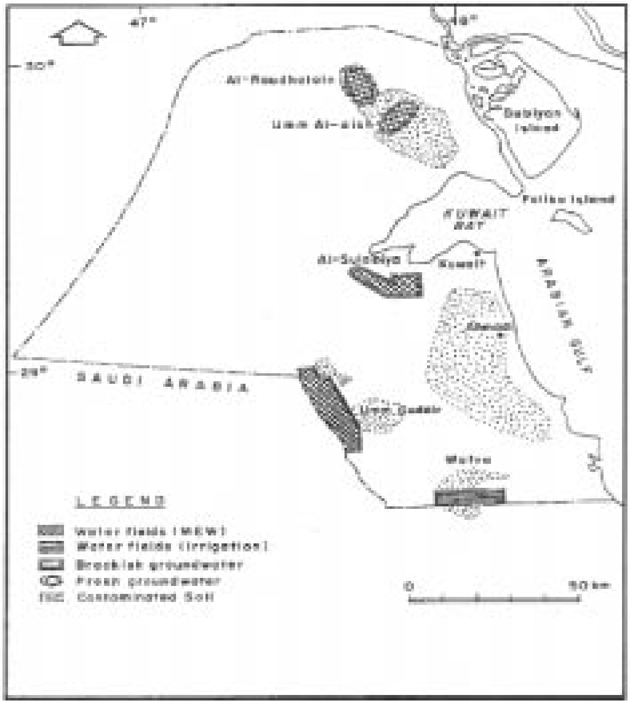

Figure 1. The contaminated areas in Kuwait including the selected study areas.

GEOLOGY AND AQUIFER SYSTEM

The territory of Kuwait extends over the discharge section of a hydrological system in which groundwater is replenished by infiltration mostly through the outcropping area of the Hasa group rocks at the north-northeastern part of Saudi Arabia and discharged into the Arabian Gulf and Shatt Al-Arab. In the natural course of the hydrological events, groundwater salinity increases gradually in the lateral flow direction towards the discharge area and becomes relatively brackish with a TDS value ranging between 2500 and 5000 ppm before reaching the State of Kuwait.

The subsurface strata in the region is divided into two geological and hydrostratigraphic units, namely, the Kuwait Group including Dibdibba, Fars and Ghar Formations, and Hasa Group including Dammam, Rus and Radhuma Formations, in a descending order. The upper units, including the saturated part of the Kuwait Group and the underlying Dammam Formation, one separated from the deeper units by mostly impervious dense anhydrite layers of the Rus Formation; however, in spite of the apparent hydrogeological heterogeneity, the system provides relatively continuous flow in the region and may be characterized as a multilayered semi-confined aquifer.

The Kuwait Group consists of the Dibdibah, Lower Fars and Ghar Formations. The Dibdibah Formation, consisting of a sequence of cross-bedded sands and gravel with subordinate sandy clay, sandstone conglomerates and silt stones, is encountered at the northern part of Kuwait. This formation also contains unique fresh water lenses beneath the Raudhatain, Umm Al-Aish and Umm Nigga depressions. The underlying lower Fars Formation is composed of fine sediments, conglomeratic sandstone, shale and thin fossiliferous limestone. The Ghar Formation consists mainly of marine to terrestrial sands, silts and gravel. The sands are generally coarse and unconsolidated. Few sandy limestone, clay and anhydrite streaks also occur in the sequence.

The saturated part of the group is regarded as the upper unit of the regional aquifer system. Owing to the lithological variation, particularly due to the percentage of clay and the degree of cementation, the Kuwait Group aquifer is subdivided into numerous hydrostratigraphic units of different permeability. Relatively high permeability values in the direction parallel to the bedding, particularly in the well-sorted sandy – gravelly zones have the most bearing on the rate of groundwater movement in the aquifer. On the other hand, the significant decrease in permeability value in the clayey and/or in the densely cemented zones as well as in the direction perpendicular to the bedding is one of the key factors controlling the pattern of groundwater flow and, consequently, hydraulic dispersion of polluted water in the aquifer, if any. Related to the nature of groundwater flow, the effective secondary porosity and the transmissivity of the Dammam Limestone aquifer decreases in the main flow direction of SW-NE, excluding the areas where the formation is locally uplifted and fractured.

GROUNDWATER FLOW

The Kuwait Group and Dammam aquifers are hydraulically connected and provide a continuous flow system. Most of the groundwater in the aquifer system originates in Saudi Arabia. The other part of the natural recharge is the infiltration through wadis and depressions scattered over the region.

In Kuwait, rainfall mostly occurs during winter, in the form of showers and thunderstorms of short duration, with an average rate of about 120 mm/yr. Evaporation ranges between a low average of about 3.3 mm/d and a high average of about 16 mm/d. Under these semi-arid climatological conditions, a considerable part of rainfall evaporates during precipitation, whereas the remaining part occupying the subsoil pores mostly evaporates through the capillary system. On the other hand, in wadis and depressions such as those in Raudhatain, Umm Al-Aish and Umm Nigga, due to run-off through the integrated drainage lines during periods of severe storms, the infiltration rate becomes comparatively high and develops a relatively significant groundwater mound on the upper saturated part of the Kuwait Group aquifer.

Under natural conditions, groundwater flows from SW to NE and discharges into the Shatt Al-Arab and Arabian Gulf through the uppermost part of the Kuwait Group aquifer. Discharge occurs by seepage below sea level and also by evapotranspiration beneath the marshlands along the shoreline and the Shatt Al-Arab, where the water table appears to be very close to the land surface. Related to the pattern of discharge, groundwater flowing through the entire thickness of the aquifer system moves gradually upwards and becomes sluggish first in the lower then in the upper zones of the aquifer system in the flow direction. Finally, it flows in the uppermost part of the Kuwait Group aquifer, over the stagnant groundwater body, in the northern part of Kuwait.

Since 1970, the natural groundwater flow regime was disturbed by the groundwater exploitation by MEW water fields in the Shagaya, Sulaibiyah, and Umm Gudair regions. As a result, the potentiometric head of the system declined gradually and, within the cone of influence, the flow direction was diverted towards the center of well fields.

Because of the observed lithostratigraphy, groundwater occurs under unconfined (water table) conditions in the topmost zone of the upper Kuwait Group aquifer and under semi-confined conditions in the deeper zones of the aquifer system. The degree of confinement increases with depth and results from the stratification and the presence of numerous zones and beds of low permeability.

GROUNDWATER QUALITY

The concentration of dissolved constituents in groundwater varies over a wide range. The pattern and the movement of groundwater, the quality of recharging water and the complicated reactions between the water and the minerals contained in the rocks are the prime factors affecting the variation in the quality of groundwater.

Under regional hydrological conditions, the concentrations of the dissolved constituents in groundwater increase towards the northeast in the direction of flow. It increases from 2500 to about 7500 ppm in the southern and the central part and sharply from 7500 to a value above 100,000 ppm in the northern and northeastern part, first in the lower then in the upper zones of the aquifer system in accordance with the sluggishness of underflow.

On the other hand, relating to the quality of local infiltration, unique freshwater lenses have been developed beneath the depressions such as Raudhatain, Umm Al-Aish and Umm Nigga over the relatively saline groundwater body.

Discussion and Results Evaluation

Groundwater under natural conditions contains different levels of the selected contaminants in the current study, which include:

1. Vanadium
2. Nickel
3. Chromium
4. Lead
5. Cadmium
6. Hydrocarbons

The naturally occurring concentration levels of these contaminants are site-specific and large variations of these are expected between different sites. Once the background levels of these contaminants are known, then it is relatively easy to determine the impact of hydrocarbon pollution on groundwater quality. The available data regarding heavy metals is limited and does not provide an adequate base for the subject evaluation. Since most of the brackish water originates from Saudi Arabia, and time of travel is between 17,000 and 23,000 years, the water quality with respect to heavy metals is unlikely to change significantly over the region of Kuwait. Therefore, heavy metal concentrations measured at Sulaibiyah and Shigaya, where there are no known sources of oil pollution, were analyzed and used a background levels in the present study.

Vanadium is present in subsurface regions mainly in magnetite and pyroxene. It also exists in concentrated forms in sulfide deposits. In groundwater, at neutral pH and reducing environments, its solubility is low with a concentration level of about 0.001 mg/L. In oxygenated groundwater its level increases to about 0.07 mg/L, and in certain hot springs, levels as high as 0.33 mg/L were observed. Maximum allowable concentration of this element in the drinking water for farm animals is 0.1 mg/L and for irrigation, it is about 0.1 to 1.0 mg/L. In the U.S., vanadium concentration levels in the municipal drinking water may reach as high as 0.07 mg/L (Leeden et al., 1990). In Kuwait crude oil, its level is about 22.5 mg/L (Speight, 1989). Analysis by Zaman and Al-Sdirawi (1992) showed that vanadium levels in soils contaminated with spilled oil varied between 15.90 and 98.60 ppm at Raudhatain and Umm Al-Aish.

Nickel is found in igneous rocks. It is absorbed by iron and manganese oxides. Its content in groundwater varies and can reach a value as high as 40 mg/L. Allowable levels of nickel in groundwater for irrigation varies between 0.2 and 2.0 mg/L. Nickel in Kuwait crude oil is about 6.0 mg/L (Speight, 1989). Studies by Zaman and Al-Sdirawi (1992) showed nickel in contaminated soils varied between 23.2 and 66.0 ppm at Raudhatain and Umm Al-Aish.

Lead exists in rocks in the earth's crust at low concentrations. Concentration of lead in groundwater is of the order 0.02 mg/L at certain locations and concentrations up to 1.2 mg/L were also observed. Cadmium is scarce element and usually occurs in association with lead and zinc. Cadmium originates from weathering of cadmium-bearing zinc minerals. It forms complexes with chloride, sulfate and chlorohydroxide ions. Chloride complexes may be important in groundwater when they have Cl contents above 350 mg/L.A major source of chromium is from man-made pollution, levels of which will depend on nature and the extent of human activity like waste disposal, landfill sites, etc. Kuwait crude oil does not contain significant levels of lead, chromium and cadmium and, therefor, these are not considered in the present evaluation.

Besides the heavy metals, total hydrocarbons were also measured in water samples to detect oil contamination in general. Hydrocarbons can occur under anaerobic conditions, particularly in oil field waters. In drinking water, a level of 0.005 mg/L is undrinkable because of the taste. Zaman and Al-Sdirawi study (1992) showed that hydrocarbons in contaminated soils at Raudhatain and Umm Al-Aish varied between 1.14 and 7.31 ppm.

The collected groundwater samples from different areas were analyzed separately by MEW, KISR and Simon lab in the United Kingdom. The collected results from different laboratories shows reasonable agreement, in general (Tables 1-5). Evaluation of water analysis data by considering all relevant factors including local hydrogeological, geological and geochemical conditions as well as the surface and subsurface soil contaminant conditions and the proximity of the monitoring sites to oil lakes show fluctuations in pollutant concentration levels. The collected groundwater samples from Raudhatain wells Nos. 50 and 63 and Umm Al-Aish wells 10, 15 and 48, which are located either in the center or adjacent to oil spill areas indicate minor oil pollution. The analyses results of these water samples show fluctuations in vanadium and nickel between 0.001 and 0.833, while hydrocarbon levels fluctuated between 0.001 and 0.190.

Well No.	Hydrocarbons ppm	Vanadium ppm	Nickel ppm
10	0.014	0.031	0.036
11	0.023	0.005	0.030
15	0.020	0.005	0.035
19	0.001	0.042	0.005
48	0.010	0.085	0.014
55	0.017	0.031	0.001
59	0.013	0.005	0.014

Table 1. The water quality results of collected water samples from Umm Al-Aish area.

Well No.	Hydrocarbons ppm	Vanadium ppm	Nickel ppm
1	0.012	0.143	0.001
5	-	0.005	0.001
6	0.008	0.017	0.005
16	-	0.005	0.005
50	0.001	0.133	0.071
52	0.100	0.010	0.010
56	0.010	0.005	0.001
63	0.030	0.004	0.006
64	-	0.833	0.001

Table 2. The water quality results of collected water samples from Raudhatan area.

Well No.	Hydrocarbons ppm	Vanadium ppm	Nickel ppm
2	0.010	0.008	0.142
10	0.010	0.019	0.005
7/TN	-	0.005	0.012
7/BM	-	0.005	0.005
7/19B	-	0.005	0.005
7/24	-	0.005	0.005
7/118	-	0.005	0.005
7/3501	-	0.005	0.015

Table 3. The water quality results of collected water samples from Wafra area.

Well No.	Hydrocarbons ppm	Vanadium ppm	Nickel ppm
4	0.001	0.005	0.031
7	0.001	0.005	0.051
17	0.007	0.013	0.011
34	0.001	0.009	0.089
42	0.001	0.005	0.012
50	0.001	0.005	0.057

Table 4. The water quality results of collected water samples from Umm Gudair area.

Well No.	Hydrocarbons ppm	Vanadium ppm	Nickel ppm
1	-	0.419	0.021
6	-	0.416	0.017
7	0.010	0.073	0.009
8	-	0.005	0.015
20	0.010	0.005	0.005
85	0.132	0.117	0.005
120	-	0.142	0.022
135	-	0.005	0.046

Table 5. The water quality results of collected water samples from Sulaibiyah area.

The available data does not provide an adequate base to substantiate the actual levels of contamination. The main factors hindering such an assessment are:

1. Most of the contaminants are likely to exist in the uppermost saturated sections, which are above the intake zone of the wells.
2. Samples collected from these wells are derived from the entire penetrated thickness of the aquifer resulting in a mixture of the polluted and non-polluted groundwater in levels varying from well to well.

Evaluation of analyses of water samples collected from other monitoring wells at the Raudhatain and Umm Al-Aish fields as well as at Wafra, Umm Gudair and Sulaibiyah do not indicate any sign of oil pollution. Non-detection of pollution from samples collected from these wells does not necessarily mean that the groundwater resources of relevant water well fields are not polluted. At the Raudhatain and Umm Al-Aish fields, where pollution of groundwater is expected, the downward infiltration might have already taken place but not yet reached the intake zone of monitoring wells during the present study period. Similarly, at the Wafra and Umm Gudair well fields, where oil pollution is expected, the sub surface leakage from the corroded and /or damaged casings of oil wells might have taken place but not yet reached the monitoring wells.

Nevertheless, the magnitude of pollution that occurred during July – October 1992 is predicted to be very minor, if not negligible; soil analyses results suggest the distinct possibility of pollution by infiltration of rainwater leaching out contaminants over a period of several years.

CONCLUSIONS

The collected groundwater samples from Raudhatain wells Nos. 50 and 63 and Umm Al-Aish wells Nos. 10, 15 and 48, which are located either in the center or adjacent to oil spill areas indicate minor oil pollution. While other monitoring wells at Raudhatain, Umm Al-Aish, Umm Gudair, Wafra and Sulaibiyah water well fields do not show pollution from oil spills. Non-detection of pollution in these monitoring wells does not necessarily mean no actual pollution of groundwater. At Raudhatain and Umm Al-Aish, groundwater pollution emanating from the infiltration of either rainwater leaching out surface pollutants or contaminated water used for fire fighting might have reached the water table levels but not the intake sections of wells, which are about 5-10 m below water table levels. Similarly at Wafra and Umm Gudair, the leakage from damaged well casings might exist but not have yet reached monitoring wells during this study period.

The present study suggests the distinct possibility of pollution from rainwater polluted by leaching of surface and subsurface contaminants resulting from oil spills and products of combustion, particularly in the Raudhatain and Umm Al-Aish depressions. Furthermore, at certain sites, this possibility is enhanced due to the increase of surface soil permeability during the removal and cleaning activities of oil lakes and oil-contaminated areas.

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