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Types and extent of soil contamination in Greater Al-Burqan oil field, Kuwait

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ABSTRACT

During the Iraqi aggression in 1990 and 1991, Kuwait's oil wells were damaged and set on fire, resulting in oil contamination of the soil. Contamination of the environment occurred from oil spreading over the land surface and penetrating the soil to varying depths, aerial fall-out from oil spray and combustion products from oil fires, and the formation of oil lakes on the land surface.

The aim of this survey was to determine the magnitude of damage in the Greater Al-Burqan oil field area (56,245 ha) for the purpose of providing information to aid subsequent land use planning and determination of remediation options.

Objectives of the survey were to categorize the types of damage, map the extent of damage, and estimate the volume of contaminated soil. An approach based on soil survey concepts was adopted. The key variables measured were contamination depth, total petroleum hydrocarbon concentrations, oil contamination concentration using laser-induced fluorescence, soil colour, soil texture, soil consistence and site location.

The reconnaissance field survey identified four observable types of oil contaminated soil layers (liquid oil, oily soil, tar mat and soot), plus a 'clean' soil type where no oil contamination was observed. The mean volume of contamination was estimated at about 24.4 million cubic meters. The bulk of the oil-contaminated soil occurs in the dry oil lake areas (70%) and the oil lake areas (24%), and oily soil is the dominant type of contaminated soil layer.

Keywords: GIS; mapping; oil contamination; soil classification; tar mat.

INTRODUCTION

During the Iraqi aggression in 1990 and 1991, Kuwait's oil wells and oil infrastructure were detonated and damaged, resulting in contamination of the soil surface and in some areas deep penetration of oil into the soil. Contamination

occurred from: 1) Oil spreading over the land surface and penetrating the soil to varying depth, 2) Aerial fall out from oil spray and combustion products from oil fires, and 3) Formation of oil lakes on the land surface.

Of the country's 914 operational oil wells, 604 were set on fire, 45 gushed oil and 149 were badly damaged (PAAC 1999). An estimated 2 million barrels of oil escaped from the damaged wells daily (PAAC 1999) and the amount of oil lost due to both the fires and oil flows has been calculated to be approximately 1.0-1.5 billion barrels (Petroleum Economist 1992). Almost 70 percent of the operational oil wells in Kuwait occur in the Greater Al-Burqan area, which includes the Maqwa, Ahmadi and Burqan oil fields. Here there were a total of 636 oil wells of which 491 were burning, 33 were gushing and 66 were damaged (Al Ghunaim 1997).

Approximately 300 oil lakes of various sizes were estimated to cover more than 49 square kilometers of the land surface in Kuwait. Of these there were 45 major lakes in Burqan and 23 major lakes in Maqwa and Ahmadi oil fields. Oil mist and soot covered an additional 1772 km² of the land surface in Kuwait (Al-Ajmi *et al.* 1994, El-Baz *et al.* 1994, Kwarteng 1998). The majority of the lakes and oil-polluted surfaces were created in the Greater Al-Burqan oil field and surroundings (Salam 1996).

The intention is to manage and restore this contaminated land. The first step, therefore, is to know the location of as well as types and volumes of contamination present. Only with this knowledge can the land use be planned and remediation options considered.

Remote sensing has been the main tool used for estimating the area and extent of contamination and to monitor changes with time. Area estimates of oil lakes in the Greater Al-Burqan area range from 14.07 km² (Al-Ajmi *et al.* 1994) to 35.45 km² (Kwarteng 1998) and 24.14 km² (Kwarteng 1999). The large variation in results is due to the different techniques employed, each with different accuracies, and also to the inherent dynamics of the oil lakes as they dry, seep away, and are covered by a sand veneer. Furthermore, the accuracies of these estimates, both of area and volume, are unknown because there has been limited ground truth data.

To estimate total volume of contaminated soil requires knowing both the area and average contamination depth of each lake. Whilst previous studies have characterized and quantified the contamination for specific sites (Al-Sulaimi *et al.* 1993, Zaman & Alsdarawi 1993, Balba *et al.* 1998), they have not estimated area and depth with sufficient accuracy and in any case too few sites have been studied to allow accurate volume estimation for the entire oil field.

Thus a field survey was designed to provide the geo-referenced, ground-truth information on the volume and extent of contaminated soils in the Greater Al-Burqan oil field at a more intensive scale than previous studies. This information

will be used to aid subsequent rehabilitation planning and monitoring, and to provide a basis for future detailed quantification surveys. Therefore the objectives of this survey were to: 1) categorize the types of damage, 2) map the extent of damage, and 3) estimate the volume of contaminated soil.

Site description

Kuwait is situated in the northwestern corner of the Arabian Peninsula between latitudes 28°30'N and 30°05'N and longitudes 46°33'E and 48°35'E. The Greater Al-Burqan oil field occurs south of Kuwait City and includes the Maqwa, Ahmadi and Burqan oil fields (Fig. 1). A security fence defines the perimeter and land use inside is restricted to oil field activities. Kuwait is characterized by a desert-type environment with low rainfall (mean 110 mm/year), extremely high temperatures during July and August (mean temperature of 37.4°C and maximum mean temperature of 45°C), short mild winters, high sunshine hours, low humidity and generally dry conditions. The surface sediments are smooth sand sheets that are normally covered with a loose thin veneer of coarse sand or fine gravel. The surface topography is a flat to gently rolling desert plain, with a few isolated hills. Soils are dominantly very deep, structureless, sandy textured, quartz soils, occasionally with calcium carbonate at depth.

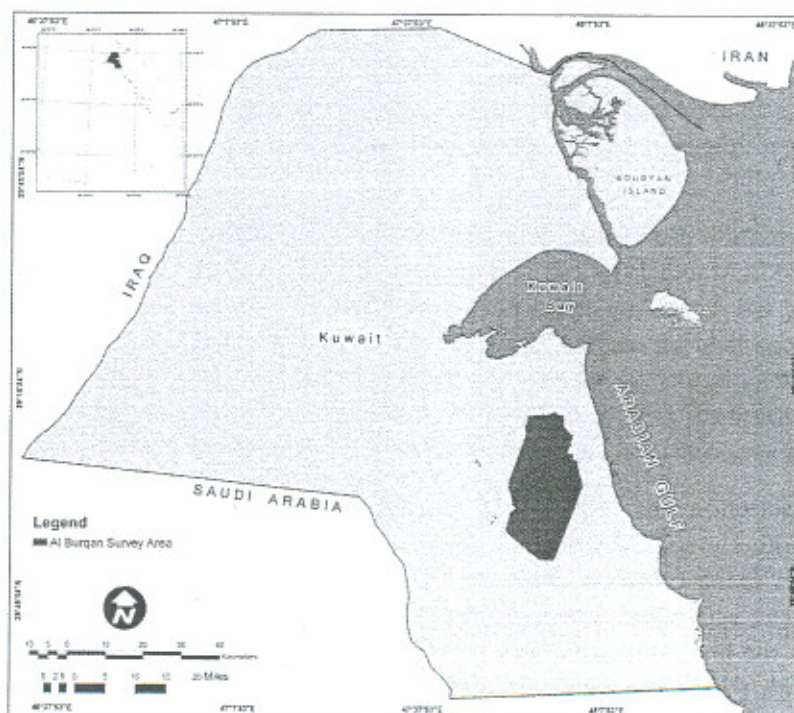


Figure 1: Location of Greater Al-Burqan oil field in Kuwait.

The area to be surveyed is large (56,245 ha) and within this area there is a wide range of contaminated conditions from oil lakes to relatively 'clean' soil by visual observance, and the contamination can vary markedly over short distances both spatially and with depth. Time constraints and available resources meant that a detailed study could not be conducted for the area, and therefore the approach was to provide a broad overview upon which future detailed surveys could use as a base.

METHOD

An approach based on soil survey concepts was adopted because this methodology is proven for mapping and providing information over a large area using a sparse site density and limited analytical data set (Soil Survey Division Staff 1993). This approach can efficiently draw on existing data sets of varying quality and combine them with the sampling data set to improve the quality of the output and to reinforce confidence in the final result. This multifaceted approach used several sources of information -- field survey observation data, remote sensed imagery, existing mapped information, laboratory analytical data and laser-induced fluorescence measurements.

Key variables measured were contamination depth (by measuring at field sites), total petroleum hydrocarbon concentrations (TPH) (USEPA 418.1 method 1988), a measure of oil contamination using laser-induced fluorescence (LIF), soil colour (Munsell colour chart), soil texture, soil consistency, landscape description (Soil Survey Division Staff 1993), and site location (using a geographical positioning system).

Information used for mapping included remote sensed Landsat TM imagery acquired in March 1998 and IRS panchromatic data acquired in February 1998, Kuwait Oil Company map 'Oil Lake EOD clearance status 27/12/98', geo-referenced field site data and field survey observations. The map linework was placed on a hardcopy image map by visual interpretation of imagery and taking into account the field data information, the linework was then digitized into the GIS for area calculations and generation of the final map.

Site selection was determined by stratifying the area based on existing maps and remotely sensed information, then systematically sampling at regular intervals along transects. Sites were also placed by surveyor experience where there were safety and access problems. There was approximately 1 site per 100 ha and the final map scale was 1:50,000. Sites occurred throughout the survey area with the higher density of sites occurring around the more contaminated locations. Very high densities of sites occurred at a few locations where oil lakes were studied and sampled in detail. No sites were located on the edges of the oil

field near the fence or in the middle of the oil field as remote sensed data indicated that these areas had limited contamination and are easily mapped with the available information from adjacent sites. 'Clean' sites for comparison were located inside and outside the survey area, on similar soils and beyond the observed contamination area.

Fieldwork commenced in December 1999 and continued throughout the winter period until May 2000. A total of 564 sites were located, described and classified. At a subset of these sites, soil was sampled for total petroleum hydrocarbon analysis (112 samples from 34 sites) and laser-induced fluorescence data (200 samples from 46 sites) that provided a measure of oil contamination equivalence.

All data was entered into a database for analysis and map information was manipulated by a geographical information system. The area for each individual map unit was calculated using the geographical information system and then those in the same map unit category were summed together. The contaminated soil volume was calculated from the area measurements with multiplication by the mean contamination layer thickness that occurred for that map unit category.

RESULTS AND DISCUSSION

The field survey identified four types of oil contaminated soil layers (soot, tar mat, oily soil, liquid oil), plus a 'clean' soil type. From the field evidence, it is clear that these contaminated layers can be separated using colour and consistence properties. Liquid oil is black and non-coherent, oily soil is dark brown to black with a moderate to slightly hard consistency, and tar mat is black with a hard consistency.

Soils are three-dimensional and layered with depth. The layer types and the organization of these layers provide information on the overall contamination category. Four contamination categories defined were oil lake, dry oil lake, tar mat, soot, plus a fifth 'clean' category where no contamination was observed. Figures 2-4 illustrate three of the four categories that can be described as follows:

- Oil lake -- consists of 1 to 70 cm liquid oil, over 18 to 100 cm (or more) of oily soil.
- Dry oil lake -- consists of 1 to 3 cm tar mat, over 1 to 179 cm (or more) of oily soil.
- Tar mat -- consists of 1 cm tar mat, over 'clean' soil.
- Soot -- consists of 0.2 to 0.8 cm soot layer in the upper soil, over 'clean' soil.

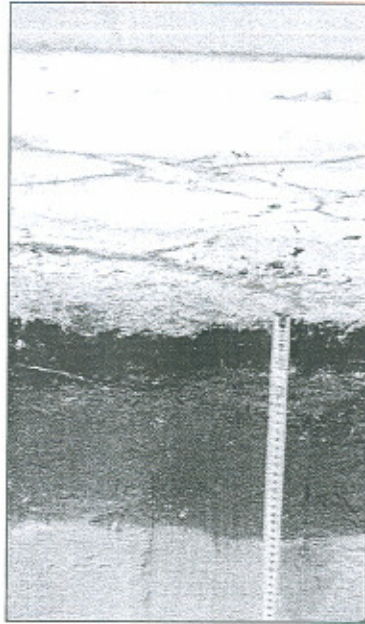


Figure 2: Oil lake category consists of a liquid or semi-solid oil layer over an oily soil.

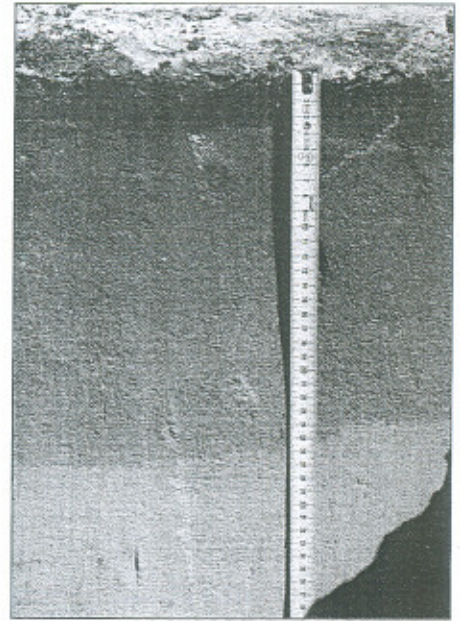


Figure 3: Dry oil lake category consists of a tar mat layer over an oily soil that has a dark brown colour, oily smell and friable consistency.

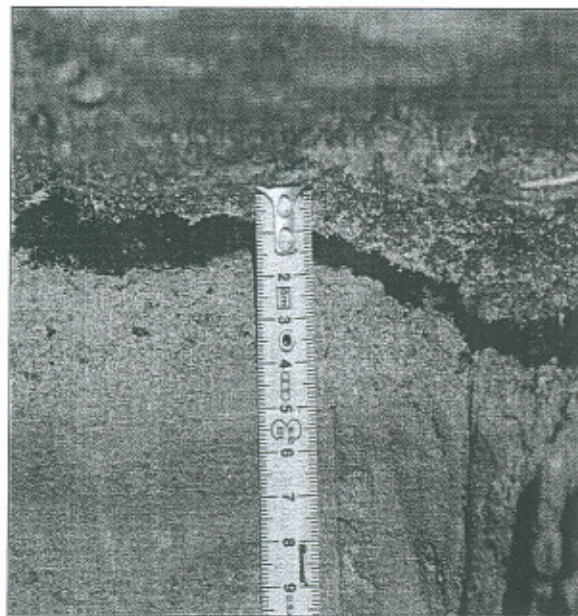


Figure 4: Tar mat category consists of a tar mat layer that has a hard consistency and can be peeled off the underlying 'clean' soil.

The map unit categories along with five other miscellaneous map units were mapped at a scale of 1:50,000 and a reduced version of the map is presented in Fig. 5. The total area for each map unit category is presented in Table 1. The largest unit is soot, followed by 'clean', tar mat and dry oil lake. The oil lake map units, where the magnitude of damage is greatest, are generally small in size, often less than 1 ha. A large number of these small size oil lakes exist now due to the original large oil lakes being subdivided by oil recovery operations and infrastructure development. Surrounding these oil lake map units are the dry oil lakes where a thickness of oil-contaminated soil remains. Tar mat and soot map unit categories are large units that occur throughout the survey area.

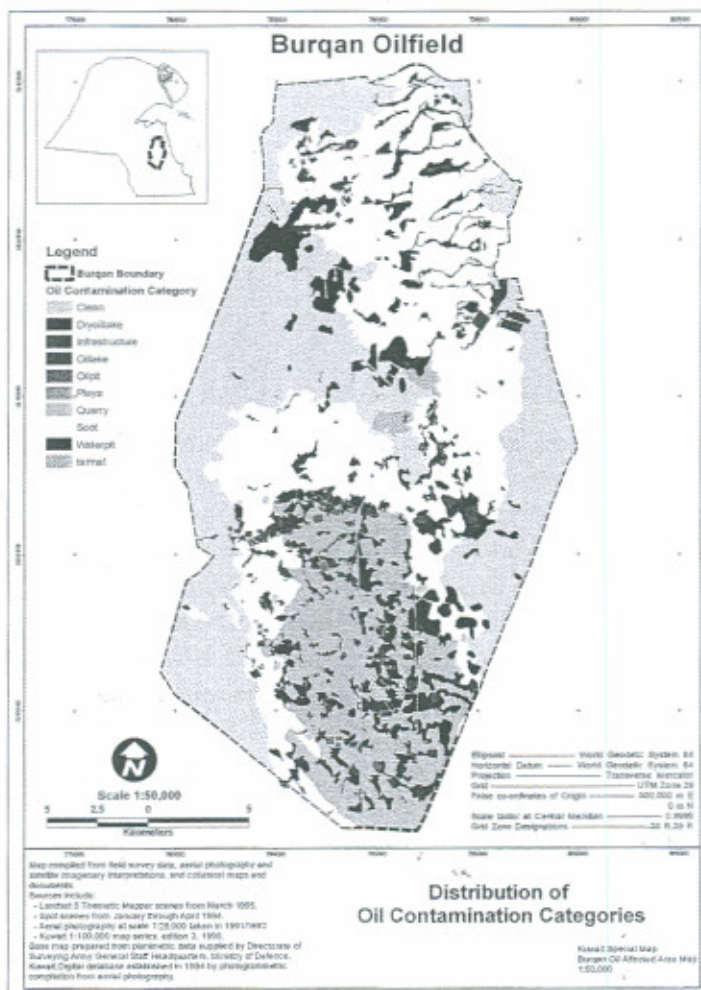


Figure 5: Reduced version of the 1:50,000 scale map showing distribution of the four oil contaminated map unit categories (oil lake, dry oil lake, tar mat, soot), a 'clean' map unit category, and five miscellaneous map unit categories (oil pit, water pit, quarry, infrastructure, quarry).

Table 1: Map unit category areas and estimates of the contaminated soil volume.

| Map unit | Area | | Volume (million m ³) | | | |
|--------------|----------|------|----------------------------------|------|------|--------------|
| | Category | (ha) | (%) | Mean | (%) | Lower bound* |
| Oil lake | 983 | 1.8 | 5.8 | 23.8 | 5.2 | 6.4 |
| Dry oil lake | 7204 | 12.8 | 17.0 | 69.6 | 14.1 | 20.0 |
| Tar mat | 8508 | 15.1 | 1.0 | 4.1 | 0.9 | 1.1 |
| Soot | 20420 | 36.3 | 0.6 | 2.5 | 0.6 | 0.6 |
| Clean | 17035 | 30.3 | ND** | ND** | ND** | ND** |
| Other | 2095 | 3.7 | ND** | ND** | ND** | ND** |
| Total | 56245 | 100 | 24.4 | 100 | 20.8 | 28.1 |

* determined as \pm SE from depth data

** not determined

The area measurements, combined with contaminated depth measurements (from 564 sites) in the map unit categories, provided an estimated average contaminated soil volume of 24.4 million m³ (Table 1). Calculating a volume in this way has inherent errors, therefore, standard errors of the depth measurements were used to provide estimates of the upper and lower volumes, which produced a contaminated volume range of 20.8 to 28.1 million m³.

The contaminated soil volume estimates (Table 1) show that the bulk of the contaminated soil occurs in the dry oil lake category (70%) and the oil lake category (24%). The oil lake map units cover a small proportion of the oil field (2%), however, they account for 24% of the contaminated soil volume. This is due to deep oil penetration into the soil in this map unit category. Even though the tar mat and soot map units are large in extent, they only comprise a small proportion of the total volume of contaminated soil (4% for tar mat and 2% for soot), because the depth of contamination into the soil of this area is very small (about 1 cm).

The type of contaminated soil is dominantly characterized as oily soil, which forms 84% of the contaminated soil volume (18% in the oil lake map unit and 66% in the dry oil lake unit). Liquid oil forms 6%, tar mat 8% and soot 2% of the total.

CONCLUSIONS

The mean total volume of oil-contaminated soil was estimated at 24.4 million cubic metres. The bulk of the contaminated soil occurs in the dry oil lake areas and oil lake areas, and oily soil is the dominant contaminated soil layer type.

Analytical results alone will not identify the different types of oil contaminated soil layers. Therefore, field observation is essential to the classification as these oil-contaminated layers have different characteristics and require different remediation or land use options (e.g. liquid oil has a weak consistency and tar mat has a very firm consistency).

This soil survey approach has been conducted on a large scale to determine the magnitude of soil damage in the Greater Al-Burqan oil field. The data gathered provides an overview of the contaminated soil characteristics and extent that can now be used as a basis for conducting future more detailed surveys to improve the quantification of the oil damage extent and volume. The data also provides base information to be used for land use planning and strategic decisions concerning remediation.

The data collected, computer database and geographical information system established in this survey is flexible and can be strategically updated with new information. This accurately located, primary information is readily retrievable for subsequent interpretation and further analysis.

For remediation the bulk of the contaminated soil to be dealt with has oily soil characteristics, and in some areas the oily soil is under liquid oil that would also need to be ameliorated. In addition, all of these areas may contain unexploded ordnance. Any method for remediation of the tar mat and soot would need to take into account that they occur over an extensive area and form a thin layer on the soil surface.

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نوع ومدى انتشار تلوث التربة في حقل البرقان العظيم، الكويت

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خلاصة

تم تدمير الآبار النفطية لدولة الكويت خلال فترة الاحتلال العراقي في عامي 1990، 1991 وسبب هذا التدمير تلوث التربة. وظهرت التلوثات البيئية نتيجة انتشار النفط على سطح الأرض وتشبع طبقة التربة على أعماق مختلفة، وتساقط رذاذ النفط الخام والنفط المحترق من الحرائق النفطية، وتكوين البحيرات النفطية على سطح الأرض.

ان الغاية من هذا المسح هو تحديد درجة الدمار في منطقة حقل البرقان العظيم (56,245 هكتار) لغرض الحصول على معلومات تساعد في تخطيط استخدام الأراضي واختيار طرق المعالجة المختلفة.

ان الهدف من هذا المسح هو تقييم نوع الدمار، عمل خرائط تبين درجة الدمار، وقياس حجم التربة الملوثة. وتم تبنى طريقة تعتمد على أسلوب مسح التربة. وتم قياس المتغيرات مثل عمق التلوث، تركيز الهيدروكربونات النفطية، تركيز النفط باستخدام الليزر الوميضي، لون التربة، ونسيج التربة وقوام التربة ومكان الموقع.

عين المسح الشبه تفصيلي أربع أنواع من طبقات التربة الملوثة (نفطية سائلة، نفطية جافة، السجاد النفطي، والسخام) بالإضافة إلى نوع التربة "النظيفة" وهي التربة التي لوحظ عدم تلوثها. وكان متوسط حجم التربة الملوثة يعادل 24,4 مليون متر مكعب. ومعظم التربة الملوثة تظهر في المناطق النفطية الجافة بمساحة (70%) والبحيرات النفطية تغطي مساحة (24%)، وهيمنت التربة الملوثة بالطبقة النفطية السائلة.

الكلمات الدالة: تصنيف التربة، الخرائط، التلوث النفطي، السجاد النفطي، نظم المعلومات الجغرافية.