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ASSESSMENT OF GROUNDWATER BELOW A CONTAMINATED SOIL LANDFILL INCLUDING MODELING OF VADOSE ZONE

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Abstract: This study aims at assessing the groundwater contamination underneath a waste yard that receives oily contaminated soil (CS). According to the collected samples from the study area, the groundwater underneath the CS site is brackish water (salinity > 40 mS/cm and TDS > 24,000 mg/L) with relatively neutral pH (7 to 7.4). Samples taken from upstream and downstream wells show high hardness (~6,000 mg/L as CaCO₃), relatively low alkalinity (50 mg/L - 80 mg/L as CaCO₃), and high sulphate content (>2,700 mg/L). The results did not show any heavy metal content. Furthermore, the amount of the different types of hydrocarbons in the groundwater samples were below detection limits of 0.01 mg/L. The infiltration of water and solute (dissolved hydrocarbons) transport have been evaluated through a one dimensional model. The computations were done using in-situ values of percolation rates and laboratory measured permeability values of compacted soils. The concentration of solute (dissolved hydrocarbons) was computed for a period of two years over a depth of 2 m below ground. The highest percolation rate observed at the dumping site was computed to be approximately 0.0007 mg/cm³ (i.e. 0.00007%). Therefore, the chances of the oil contamination reaching the water table are remote.

1 INTRODUCTION

Oil companies generate significant quantities of oil contaminated soil (CS) due to different activities including oil leaks/spills. This CS is stockpiled at different waste facilities (with environmental permits) located within the specific concession zones. Currently, there are no clear standards about soil contamination in Oman. However, the sites have to be assessed for the level of contamination (mainly hydrocarbons and heavy metals) and possible migration of contaminants to the surrounding environment (mainly to groundwater). There are no water monitoring wells in the nearby areas of the CS sites. This can be attributed to the remote nature of the CS sites and the depth of groundwater (>30 m below ground level). However, there is an important need to monitor the groundwater quality underneath the CS sites (especially the most vulnerable sites). Moreover, studies are needed to treat the contaminated soils in order to reuse them in different beneficial applications (e.g., road construction). This study aims at assessing the groundwater contamination underneath a waste yard that receives oily CS and model the solute transport through the unsaturated zone underneath the study area.

2 CHARACTERIZATION METHODOLOGY OF GROUNDWATER

This task involved collection of representative samples from the groundwater underneath the CS site. Water sampling standard procedures developed by USEPA were used as a guiding procedure for the groundwater sampling activity. Two boreholes at the study area were installed; upstream and downstream of CS site based on groundwater flow direction. Groundwater samples were collected from the installed boreholes in

the CS site over a period of six months. Complete physical-chemical analysis was conducted on the collected samples over the period of this study.

3 INSTALLATION OF BOREHOLES WITH GEOTECHNICAL INVESTIGATION

The geotechnical investigation consisted of drilling and installation of wells for groundwater monitoring. The wells were located upstream (Borehole 1) and downstream (Borehole 2) of the dumping site (Figure 1). The field work started on May 21, 2016 and finished on May 31, 2016. Two wells were installed to a depth of 50 m. The installation of the wells consisted of the following steps:

1. Drilling of a shallow hole of diameter of 12 ¼" to a depth of 5 m. The purpose of this hole is to house the well cap (well head) and to prevent the entry of surface flow through the annulus between the well and native soil.
2. Installation of a 9 5/8" dia MS casing to a depth of 5 m below ground surface. The annulus between this casing and the native soil was filled with cement grout.
3. Drilling of a deep borehole of diameter 8 1/2" below the surface of the MS casing and up to a depth of 50 m.
4. Installation of a 4" HD UPVC screen/casing from a depth of 0.70 m to a depth of to 50 m. The casing has a sand trap bottom plug.
5. The annulus between the 4" casing and drilled hole was filled with gravel, sand, bentonite seal and cement grout.
6. Performance of well development.
7. Installation of well head cap.



Figure 1: Locations of the boreholes with respect to CS site

The soil profile exposed in the boreholes generally consists of claystone underlain by argillaceous limestone grading into marly limestone and marl stone with depth (See Figure 2). The claystone extends from the

ground surface up to a depth of 4 to 5 m below the ground surface. The claystone is reddish and of low strength. Argillaceous limestone extends below the claystone up to a depth of about 14 m in borehole BW1, and to a depth of 12 in borehole BW2. The limestone is off white and of low to moderate strength. The limestone is grading into marly limestone up to a depth of 31 m in borehole BW1 and to a depth of 28 m in borehole BW2. The marly limestone is off light to reddish and of low strength. The marly limestone changes to marl stone below the depth of 31 m in borehole BW1 and below 28 m in borehole BW2. The marl stone extends up the bottom of the boreholes (i.e., 50 m). The marl tone is reddish and of low strength. In terms of strength, all these are of low strength, except the argillaceous limestone which showed moderate at some depths. This is evidenced from the records of drilling. In terms of hydraulic conductivity, all these formations have low values, especially the claystone and the marl stone. The water strike was encountered at a depth of 42.5 m in BW1 and 43 m in BW2. The wells were developed using a pumping rate of 2.8 m³/hr. After pumping, the water level in the wells was 24.5m and 24.8 m below the top of the casing in BW1 and BW2, respectively.

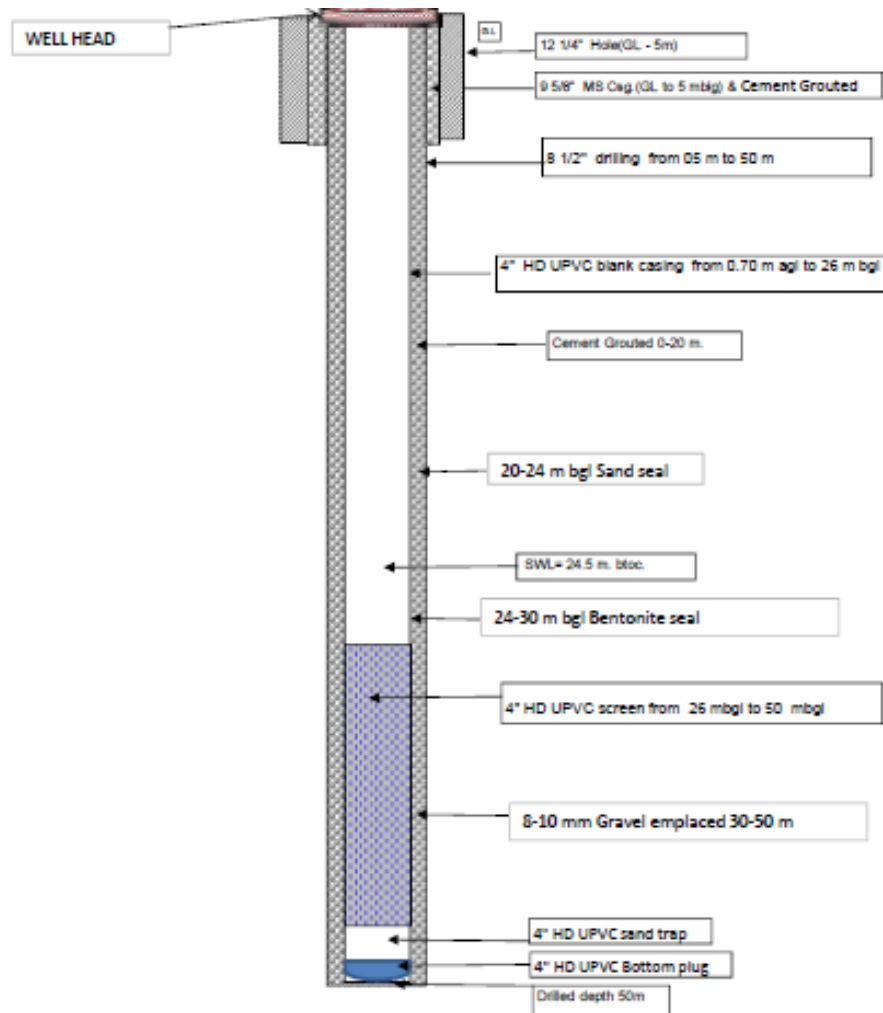


Figure 2: Borehole 1 upstream of the CS site

4 CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES

4.1 Analysis of Soils Samples

Analysis studies have been conducted for 8 soil samples from the CS site following standard methods of USEPA. The pH value of the CS samples ranged from 7.9 to 11.3. The results of leachate analysis for heavy metals in CS samples such as selenium, cadmium, lead, cobalt mercury showed that the concentrations are below the detectable limits except for Manganese concentration which ranged from 0.76 to 1.65 mg/L. The results of most volatile organic compounds for CS samples were also below the detectable limit except for butyl benzene group showing concentrations more than the detectable limits ranging from 0.02 mg/kg to 0.97 mg/kg (i.e., less than 0.0001%). Further, the analysis of petroleum hydrocarbons namely C6 and C7 in CS samples showed slightly higher in concentration than the detectable limits (0.01 to 0.82 mg/kg). The analysis of C10 to C28 concentrations for all CS samples ranged from below the detectable limit of 0.05 mg/kg to a maximum value of 590 mg/kg. Overall, the total mass concentration of C10 to C28 in CS was found around 2,400 mg/kg (0.24%). The concentration of the heavy fraction (>C28) of the petroleum hydrocarbons in the CS samples ranged from 9,100 mg/kg to 19,990 mg/kg (i.e., 0.91% to 2.0%).

4.2 Groundwater Results

Groundwater samples were collected in June, July and November, 2017 from BW1 and BW2 (Table 1). The closest groundwater underneath the CS site existed at approximately 50 m below ground surface in both upstream and downstream directions. According to the collected samples, the existing groundwater is very saline water (salinity > 40 mS/cm and TDS > 24,000 mg/L) with relatively neutral pH (7 to 7.4). Both samples taken from upstream and downstream wells show high hardness (~6,000 mg/L as CaCO₃) and relatively low alkalinity (50 mg/L to 80 mg/L as CaCO₃). The sulphate content is very high (>2,700 mg/L). The results did not show any heavy metal content. Furthermore, the amount of the different types hydrocarbons (TPH as C5-C9 and C10-C40, VOC, PAH and BTEX) in the groundwater samples (upstream and downstream directions) were below detection limits of 0.01 mg/L).

Since all samples taken from the boreholes upstream and downstream of the dumping site did not show any contamination of hydrocarbons, it can be concluded that no hydrocarbons have leached from the CS dumping site. These findings support the outcomes of Phase 1 of this project which showed that the hydrocarbon contamination in the CS is more of a heavy fraction that is unlikely to leach or mobilize from the site. Furthermore, there is no need to model any transport of hydrocarbons in the groundwater (saturated zone) as the risk of groundwater contamination is absent.

However, modeling of solute (hydrocarbons) transport through the unsaturated zone (ground surface to water table) is needed to demonstrate the possibility of contaminant migration through the soil to underneath layers (next section).

Table 1: Chemical Analysis of Groundwater samples from BW1 and BW2

Test	BW1			BW2		
	Jun 2017	Jul 2017	Nov 2017	Jun 2017	Jul 2017	Nov 2017
Alkalinity, as CaCO ₃ , mg/L	65	53	57	63	78	61
Bicarbonates, mg/L	79	65	69	76	95	74
Calcium, mg/L	1443	1423	1436	1303	1303	1073
Calcium Hardness, mg/L	3600	3550	3583	3250	3250	2677
Carbonate, mg/L	<1	<1	<1	<1	<1	<1
Chlorides, mg/L	15127	16881	15889	12226	13991	13417
Conductivity, mS/cm	49.6	51.9	46.5	44.1	45.4	40.1
Copper, mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

Fluoride, mg/L	1.63	1.54	1.6	1.82	1.56	1.72
Iron, mg/L	0.04	<0.02	0.02	0.05	<0.02	0.03
Magnesium, mg/L	778	778	798	693	644	786
Magnesium Hardness, mg/L	3200	3200	3284	2850	2650	3235
Manganese, mg/L	0.02	0.02	<0.02	0.03	0.04	<0.02
Nitrate, mg/L	-	15.3	16.9	-	16.3	9.8
pH value @ 25°C	7.4	7.4	7.0	7.4	7.2	7.1
Potassium, mg/L	437	243	186	471	225	158
Sodium, mg/L	7525	9880	8200	6640	8735	7210
Sulphate, mg/L	3055	3243	2850	2778	3175	2700
Total Dissolved Solids, mg/L	29140	32500	28970	26460	28180	24902
Total Hardness	6800	6750	6866	6100	5900	5871
Zinc, mg/L	<0.1	<0.1	<0.1	<0.1	0.11	<0.1
VOC, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C5-C9, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C10-C40, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PAH, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BTEX, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

5 NUMERICAL MODELING OF SOLUTE TRANSPORT IN UNSATURATED SOIL

The vadose (unsaturated) zone may be composed of consolidated rock and/or unconsolidated granular material. Contamination of the vadose zone can result from many sources, including leachate from waste disposal sites. The vadose zone fluid transport model is based on the conceptualization of (1) the relevant processes (for example diffusion and advection), (2) the structure of the subsurface, and (3) the potential events or scenarios (like rainfall or flood events) that impact the behavior of the modeled system. These conceptualizations together form a "conceptual model". Therefore, a conceptual model can be defined as an evolving hypothesis identifying the important features, processes, and events controlling fluid flow and contaminant transport of consequence at a specific field site in the context of a recognized problem (Hsieh, 2001).

5.1 Soil Properties

The available Geological information suggests that the proposed site is located on the outcrops of sub recent deposits comprising gypsiferous silt, sand, gravel with some cobbles with a thin veneer of Aeolian sand. So, the contaminated soil dumping sites may consist of two layers; the upper layer comprises of Aeolian sand and the lower layer may be considered as sandy gravel.

5.2 Climate

The study area is located in arid zone with the following conditions: 1) range of mean monthly high temperature of 27 to 46 °C, 2) range of mean monthly low temperature of 11 to 27 °C, and 3) mean annual rainfall of 35 mm.

5.3 Modeling of Solute Transport in Unsaturated zones

5.3.1 Modeling process

The modeling process of solute transport through the vadose zone starts with the collection of all the relevant data regarding the soil, climatic conditions and the physical processes occurring at the study site. The objective of the study governs the setup of the conceptual model which includes the site specific physical, chemical and climatic data. The mathematical model is built upon the conceptual model.

5.3.2 Mathematical model for unsaturated zone

The mathematical models for flow of water and solute transport in unsaturated zone has been a topic of interest since long time. Oster (1982) has presented the relevant theory and reviewed 55 mathematical models for a flow and transport of solute in unsaturated zone. The models were listed based on the following factors: 1) documentation, 2) applications, and code availability. The list of models include a range of models from simple solutions of one-dimensional Richard's equation to three-dimensional numerical models. The number of required input parameters and complexity of the models increases with the number of dimensions in the models.

5.4 Utilized Software

In order to carry out the numerical modeling of the infiltration of water and solute (soluble part of the petroleum hydrocarbons which is assumed to be derived from the contaminated soil) a one-dimensional model namely HYDRUS-1D is used. This program numerically solves the Richard's equation for saturated-unsaturated water flow and advection-dispersion type equations for heat and solute transport. The HYDRUS-1D code may be used to simulate water and solute movement in unsaturated, partially saturated, or fully saturated porous media. The flow region itself may be composed of nonuniform soils (Šimůnek et al., 2013).

The model domain comprises of a vertical distance from the ground surface to 2 m. This depth was selected after making several trials to observe the variation of water head and the solute concentration profile. As the domain becomes larger, the variation of the hydraulic head and concentration cannot be clearly observed, due to an extremely small hydraulic conductivity the variations remain very close to the surface. A constant pressure head based on the field capacity of the soil varied from -100cm to -340cm (for different sites) was imposed at the ground surface and the solute concentration of 0.01 mg/cm^3 (0.001%), the maximum value achieved for soluble petroleum hydrocarbons (n-hexane compounds) in the CS site. The values of heavier hydrocarbons are smaller than this value. Therefore this value was adopted in the modeling. The solute concentration was imposed at the ground surface for a duration of 10 days owing to an estimated duration of rain in a year. The average annual rainfall was around 35 mm in the study area. However, the maximum rainfall has reported to be more than 140mm. The information about the runoff is not available.

The model is run based on the ponding of the contaminated soil site for a period of 10 days and for that the actual percolation rates measured on the site are used. The theoretical recharge rate may be estimated as a percentage of the mean annual rainfall. In many places in the Sultanate of Oman the recharge rate has been found to be 10 to 15% of the amount of rainfall. Using these figures, the recharge rate can be estimated to be 2 mm to 4.5 mm per annum. The depths from ground surface at which hydraulic head and solute concentrations are plotted for N1, N2, N3 and N4 which correspond to 12, 72, 140 and 200 cm, respectively. The model was run for a duration of two years to observe the variation of fundamental properties (hydraulic conductivity, moisture content and solute concentration). A longer duration could be selected, however, for the preliminary calibration efforts, two years of simulation is appropriate.

5.5 Model Results

The in-situ percolation tests done in the field showed percolation rate of 1987.2 cm/d. The computations were done for the dumping site using the solute concentration of 0.01 mg/cm^3 (0.001%) at ground surface. The results showed that the maximum concentration of the solute at 2 m below ground after two years was found to be approximately 0.007 mg/cm^3 (0.0007%) (Figure 3).

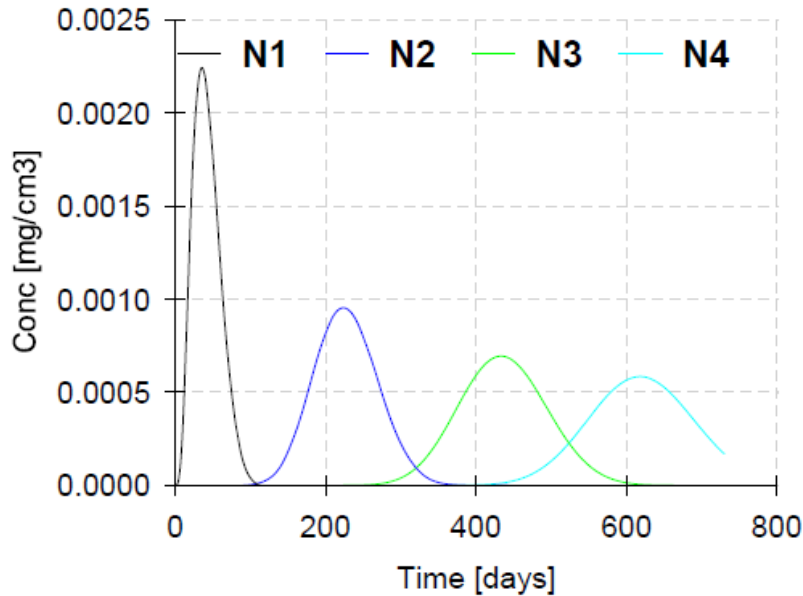


Figure 3: Solute concentration versus time for in-situ percolation rate at the CS site

6 CONCLUSIONS

Field visits and sampling process were conducted for groundwater underneath for a CS site in Oman. The collected samples include groundwater from boreholes upstream and downstream of the dumping sites over three different months. The investigations involved chemical characterization of collected groundwater samples for each borehole. Also, a modeling of the solute transport in the unsaturated soils underneath the CS sites was conducted.

The obtained results of the different types hydrocarbons ((TPH as C5-C9 and C10-C40, VOC, PAH and BTEX) in the groundwater samples (upstream and downstream directions) were below detection limits of 0.01 mg/L). Hence, it can be concluded that no hydrocarbons have leached from the CS in the dumping site.

A well-known model for flow and solute transport in variably saturated porous media has been applied to study the infiltration of water and solution transport at oily sand dumping site. The computations were done using in-situ values of percolation rates. The concentration of solute was computed for a period of two years over a depth of 2 m below ground. The concentration of solute 2 m below the ground after two years was predicted to be 0.0007 mg/cm³ (0.00007%) approximately. Therefore, the chances of the oil contamination reaching the water table is remote considering the fact that the minimum distance among the studied locations from the ground surface to water table is 50 m.

6.1 References

- Hsieh, P.A. 2001. Conceptual Models of Flow and Transport in the Fractured Vadose Zone, P.A. Hsieh et al. (eds), National Academy Press, Washington D.C., USA.
- Oster, C. A. 1982. Review of Ground-Water Flow and Transport Models in the Unsaturated Zone, Report No. NUREG/CR-2917 PNL-4427, U.S. Nuclear Regulatory Commission, Washington, D.C., USA.
- Šimůnek, J., Šejna, M., Saito, H., Sakai, M., and van Genuchten, M. Th. 2013. The HYDRUS-1D Software Package for Simulating the One-Dimensional Movement of Water, Heat, and Multiple Solutes in Variably-Saturated Media, Department of Environmental Sciences, University of California Riverside, Riverside, CA 92521, USA.