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Soil and Groundwater Contamination due to Leaking Underground Fuel Tanks (UFT) in Saudi Arabia

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Abstract: Gasoline is a complex contamination agent, which may be originated from a variety of contamination sources. Sources may include, among others, leakage of underground fuel storage tanks in gas stations and large farms. Identifying and quantifying the soil and groundwater contaminations due to leakage from the underground gasoline tanks are of primary importance in providing better regulations to protect the environment. This subject has not received much of researchers' attention in the Gulf area which is recognized by its huge oil production industry.

In AlQassim region of Saudi Arabia, most of the existing gas stations are more than 25 years old when the region started its development era. There were no environmental regulations for constructing the gas stations and the technology used for the underground gasoline tanks is outdated compared with the nowadays technology. Therefore, it is expected that soil and/or groundwater contamination has been taking place for years.

The current research presents an attempt to assess the risks associated with soil and groundwater contamination due to gasoline leakage from underground fuel tanks. A geo-environmental investigation is conducted for two gas stations in the City of Buraidah, the largest in AlQassim region. The results of the study showed that there is an actual case of gasoline leakage which led to soil contamination with gasoline substances. This soil contamination might also threat the groundwater resources in the region due to the leaching phenomenon. The study draws the attention of the authorities to the seriousness of this problem and the importance of starting a remediation process to overcome the problem.

Keywords: Saudi Arabia, AlQassim, soil contamination, groundwater contamination, underground fuel tanks.

1. Introduction

Gasoline is a complex contamination agent, which may be originated from a variety of contamination sources. Sources may include, among others, leakage of underground fuel storage tanks in gas stations and large farms. Identifying and quantifying the soil and groundwater contaminations due to leakage from the underground gasoline tanks are of primary importance in providing better regulations to protect the environment.

In AlQassim region of Saudi Arabia, most of the existing gas stations are more than 25 years old when the region started its development era. Not only that but rural farms in the region depends in its fuel supply on underground fuels tanks. The technology used then for the construction of the stations as well as the underground gasoline tanks are outdated and did not consider the appropriate international standard environment protection regulations. While this subject has received much of the researchers' attention in other countries (US and Europe), it has not yet received the same attention in the Gulf area, which is recognized by its huge oil production industry. Therefore, it is expected that soil and/or groundwater contamination has been taking place and accumulating for years. Following, we will present some of the reported cases of soil/groundwater contamination with gasoline products due to UFT.

In the USA, storage tanks for vehicle fuel and heating oil are common on farms and rural residences nationwide. These underground tanks historically have been constructed of steel, and over the years tens of thousands of the tanks have corroded and leaked petroleum products into soil and groundwater. Underground tanks are also subject to spills when refilling or pumping. Even small leaks can add up to big problems. A significant extensive study (ten years long) in that field sponsored by the California State Water Resources Control Board (SWRCB), Underground Storage Tank (UST) Program was published in 1995 [1]. The goal of the study was to collect data about the fate and transport of Fuel Hydrocarbons (FHC) released into California's diverse hydrogeologic settings and the impacts these releases may have on groundwater resources. The study investigated the FHC plumes, the factors that influence the length and mass of FHC plumes, the extent of the FHC plumes impact on groundwater resources, and the results of the remediation process of the contaminated sites. Plume lengths were defined using a benzene concentration of 10 ppb (parts per billion). The study involved 5700 contaminated sites in the state of California. For each site, a time series of estimated benzene plume lengths, average benzene concentrations, and groundwater data were determined. Borehole logs were used to identify soil lithologic types present at the site. The study showed that Sixty three percent of the sites showed a relationship between increasing TPHg and decreasing O_2 groundwater concentrations. The study showed that plume's geometry tends to change slowly with time. In general, plume lengths change slowly and tend to stabilize at relatively short distances from the FHC release site and an active remediation helps reduce plume mass. The results also indicated that 16% of the well characterized sites were found to have average benzene concentrations greater than 10 ppb, while 42% of the sites had stable plume lengths. This finding may be expected because plume concentrations tend to decrease more rapidly and frequently than plume lengths, and there is a greater probability of finding a stable plume length than a stable plume concentration. The study presented a detailed comprehensive model for detecting, estimating, and remediation of groundwater contamination sites. The study also presented few techniques for remediation such as over-excavation, and pump and treat. Some of the important conclusions drawn from the study were; over-excavation can reduce the likelihood of benzene getting into the groundwater in high concentrations, especially in sites with shallow groundwater. Application of pump and treat technique may increase the chances of significantly decreasing trends in average plume concentration, and over excavation technique may further increase the chances. Plumes at sites with very shallow groundwater almost never show increasing lengths, while those at sites with relatively deep groundwater are more likely to grow; which is the case of groundwater conditions in AlQassim. This study led to overall changes in the technology used to construct underground fuel tanks in the USA and the regulations that control them as well as the remediation procedures.

In a report published by the State of Wisconsin Department of Commerce, it was mentioned that the underground gasoline tanks begin leaking after 12 to 17 years [2]. They also mentioned that a tank leaking one drop every 10 seconds could release 60 gallons per year and it takes only a few quarts of gasoline to severely contaminate soil/groundwater causing environmental and health problems [2]. Figure (1) shows a schematic diagram for a leaking underground fuel tank and the associated potential risk [2]. Figure (2) shows a removed damaged underground tank in the state of California, USA [3]. The two figures clearly show why people and authorities should be very concerned.

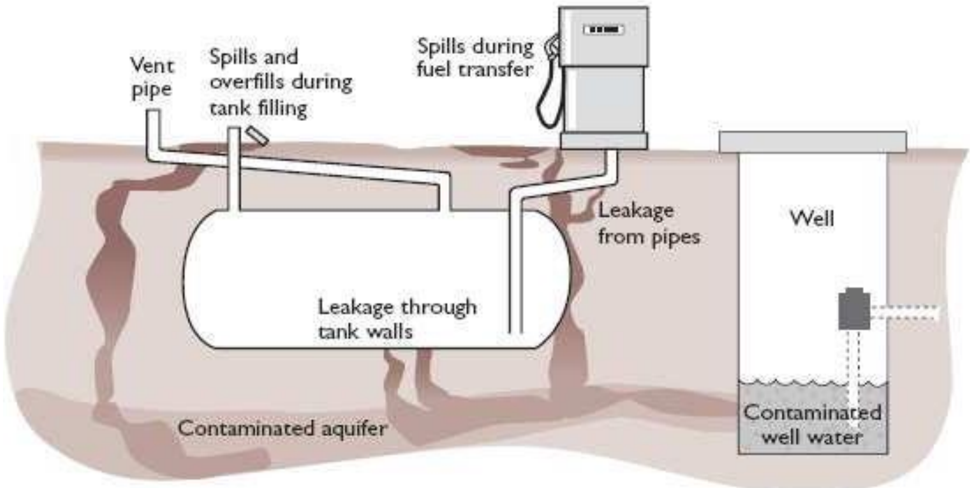

Figure (1). A schematic diagram for a leaking underground fuel tank in a gas station. [2]

Figure (2). A damaged underground fuel tank in California, USA. [3]

The USA Federal Emergency Management Agency (FEMA) has known since at least the 1990s that tanks under its supervision around the country could be leaking fuel into soil and groundwater [3]. The FEMA tanks are part of a larger problem. More than 500,000 leaking storage tanks – most of which are filled with fuel and oil – are buried across the country. Because they're underground, leaking tanks can go undetected for years. If diesel leaks into drinking water, affected people could be at a higher risk of cancer, kidney damage and nervous system disorders. A gallon of fuel can contaminate 1 million gallons of water[3].

The common life expectancy of buried benzene tanks is 10-15 years. At about 20 years, the risk of leaks from buried steel oil tanks becomes significant [4]. Leaks can occur earlier if a tank was damaged at installation or was not properly piped. The same reference presented probable causes for underground fuel tank leaks such as; in-tank corrosion, external rust, corrosive soils, leaking of buried piping connections, and delivery and in-door spills. In the State of New England, for a two year period [1984-5] among customers who have buried heating oil tanks (16% of total customers) surveyors found an average of 1.7 oil tank leaks per thousand customers. The researchers studying these oil tank leak rates also found 2.5 fuel line leaks per 1000 oil heating customers [5]. Shih *et al*. (2004) investigated the impact of fuel hydrocarbons and oxygenates from leaking underground fuel tanks on groundwater resources [6]. The study evaluated the potential for groundwater resource contamination by fuel hydrocarbons (FHC) and oxygenates (e.g., *tert*-butyl alcohol [TBA], *tert*-amyl methyl ether [TAME], diisopropyl ether [DIPE], ethyl *tert*-butyl ether [ETBE], and methyl tert-butyl ether [MTBE]) by examining their occurrence, distribution, and spatial extent in groundwater beneath leaking underground fuel tank (LUFT) facilities. The data was collected from over 7200 monitoring wells in 868 LUFT sites from the City of Los Angeles, California, USA. The study results demonstrated that MTBE poses the greatest problem, followed by TBA and benzene. Day *et al*. (2001) investigated the fate and transport of fuel components below leaking underground storage tanks (LUFT) in the City of Denver, Colorado, USA [7]. They stated that leak detection is primarily dependent on physical measurement systems that are generally capable of detecting leak rates as small as 0.2 L/h. The risk was evaluated by modeling fate and transport of fuel components from small LUFT leaks. It was found that small leaks do have the potential to impact shallow groundwater. They concluded that routine monitoring of shallow groundwater should be a component of a leak detection program, particularly in high-risk areas. Corapcioglu (1987) and Baehr (1987) introduced compositional multiphase model for groundwater contamination by petroleum products and solved numerically utilizing numerical analysis technique [8], [9].

Several studies were conducted to investigate the mechanism by which the spilled or leaked fuel transports through subsurface soil layers if effective investigative and remedial measures are to be implemented. As mentioned by Rice *et al*. (1995), once liquid FHC are released into the subsurface, they percolate through the unsaturated zone soil pore spaces, at first under the force of gravity. The lithologic heterogeneity, moisture content, and permeability of the soils determine the amount of liquid retained in the soil and the extent of the lateral spreading of liquid and gaseous hydrocarbons. As liquid- and gaseousphase FHC move through the unsaturated zone, they will follow the path of least resistance. When dense, low permeability layers are encountered, the bulk FHC liquid flowing under the force of gravity will tend to spread [10]. A portion of the FHC mass will adhere onto soil particulates [11] or simply lodge in pore throat necks and dead-end pore spaces [12], [13]. The amount of FHC adhered onto soil particulates is dependent on the amount of organic material and type of minerals present in the soil matrix [11].

All the above mentioned literature emphasizes the seriousness of this problem and that it has been under investigations by researches in the USA for years. Therefore it is about time that it gets the appropriate attention in the Meddle East in general and Saudi Arabia and the gulf area in particular. The current study aims only at shading the light on the problem in order to grab the attention of authorities, researchers, and funding agencies to look deeply into the problem. The study is the first step among a series of studies which will be conducted in the future which hopefully shall lead to improving the environmental protection regulations in AlQassim.

2. Methodology of Study

The program of the study involves conducting a field study of the gas stations that exist within the limits of the City of Buraidah, AlQassim. The objective of the field study is to collect data about gas stations including age of the stations, ownership, frequency and method of fuel refilling, type of fuel, and any information about spill accidents. This information is statistically analyzed, and the results are presented in the form of the appropriate tables and figures. Following, two of the oldest gas stations studied were selected to conduct a geo-environmental study in order to determine the status of soil and groundwater within the sites of the selected gas stations. Four boreholes (10 m depth) were executed; two at each site, and soil samples were collected at an interval of 1.0 m or at change of soil nature. The collected soil samples were tested in the laboratory to determine the nature of soil at the sites. The water table couldn't be reached during the boreholes excavation and consequently there were no collected groundwater samples. The soil samples are then chemically tested in order to examine the existence of any traces of benzene contamination or any of its substances. The concentration of the existing harmful substance, if any, was determined in the form of a percentage by weight of the tested sample. Figures (3) and (4) show the locations of the two selected sites for the study. The figures also show that the two gas stations are constructed nearby residential areas which means that there is an actual environmental threats to the health and of the people living in the area.

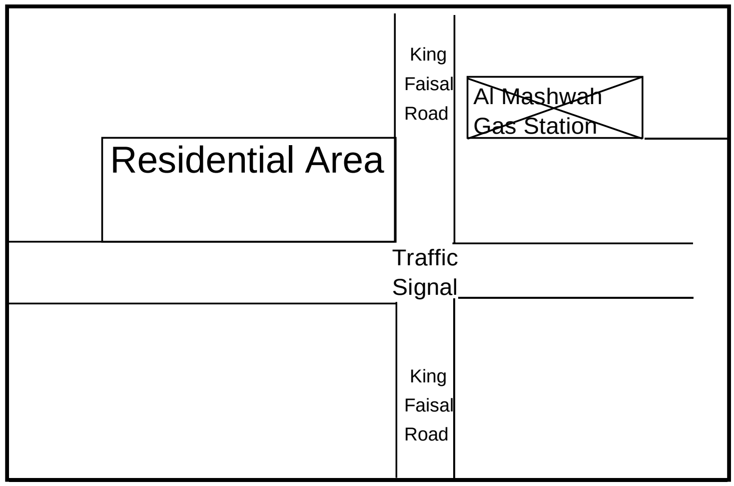

Figure (3). The location of the first gas station in the City of Buraidah.

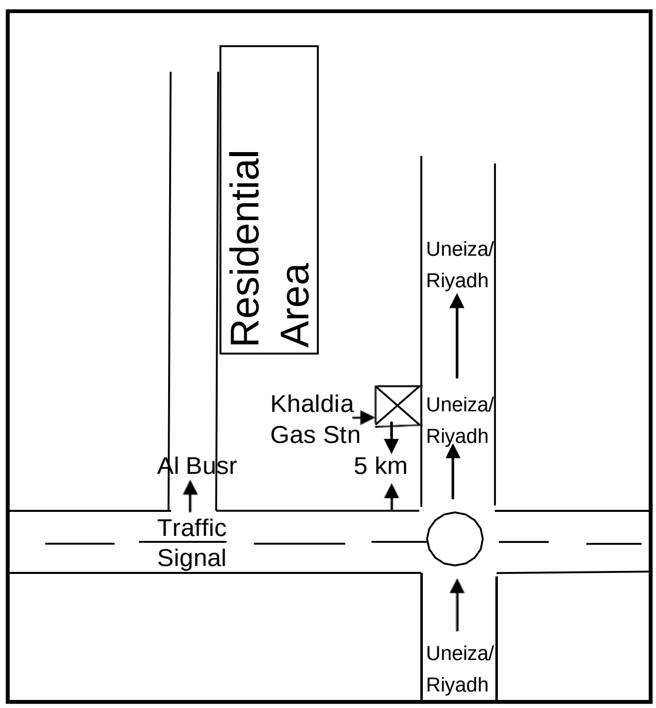

Figure (4). The location of the second gas station in the City of Buraidah.

3. Results and Discussion

3.1 Soil profile

The visual description of the collected soil samples at the two investigated sites showed that the soil profile tends to be of sandy soil with traces of gravel in some areas. The samples were subjected to grain size analysis in order to determine its nature and particle size gradation. The results of the lab tests showed that the soil profile at both sites are composed of surface soil of silt and sand with a varying thickness of 0.5 – 1.0 m. The successive soil layers were found to be graded sand from medium to course with traces of silt and gravel at various depths from ground surface. These soil layers are characterized of high permeability which ranges from 10^{-1} – 10^{-3} cm/s which reflects the high infiltration rate of rain water fall. Figure (5) shows the general soil profile at the investigated sites.

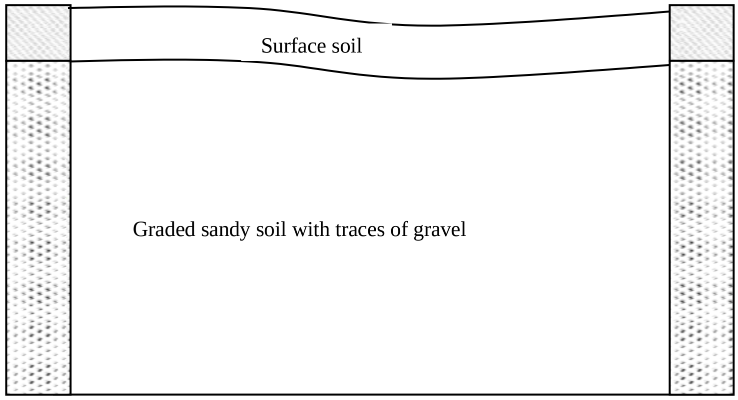

Figure (5). The general soil profile at the sites of investigation.

3.2 Results of chemical tests

The chemical tests were conducted on the soil samples collected at two levels from ground surface (4.0 and 6.0 m). Almost all collected soil samples were observed to have flammable solvents in appreciable amount. In particular samples of BH-03 and BH-04 have high flammable solvents; where as samples of BH-01 and BH-02 have higher hydrocarbons content.

The objectives of the chemical tests were to investigate the existence of any harmful chemical compounds and determine its percentages by weight of the soil samples weight. The investigated harmful compounds include benzene and/or diesel fuel, and any of their substances specially hydrocarbons. Examples of investigated compounds include but not limited to; Dodecane, Tridecane, and Pentadecane which are chemical compounds that consist only of the elements carbon I and hydrogen (H) (i.e., hydrocarbons), wherein these atoms are linked together exclusively by single bonds (i.e., they are saturated compounds) without any cyclic structure (i.e. loops). These compounds are known to be harmful and may cause lung damage if swallowed. They also may be harmful by inhalation or skin absorption, or act as an irritant [14]. Tables (1) and (2) show the results of the chemical tests conducted on the soil samples in the form of % by weight, of the soil sample, of the harmful hydrocarbon compounds.

Table (1). Results of the chemical tests conducted on the soil samples collected at Gas Station (1) at 4.0 and 6.0 m depths.

Test Parameters	% of hydrocarbons by Wt of Soil Samples	
	BH-01 Depth 4.0 m	BH-02 Depth 6.0 m
Dodecane $$ n-Dodecane-C12H26	0.234581	0.685269
Tridecane C13H28	0.785965	1.023695
Tetradecane-C14H30	1.235680	3.263851
Pentadecane-C15H32	2.358640	5.036925
Heptadecane-C17H36	2.012530	6.369810
Heneicosane-C21H44	3.256480	2.023689
Heptadecane-C17H46	2.365810	8.326981
Heneicosane-C21H44	4.359820	8.301200
Hexadecane,2,6,10,14-tetramethyl-C20H42	1.356820	1.235680
Nonadecane-C19H40	3.256980	8.156840
Eicosane-C20H42	4.356958	7.123580
Tetracosane-C24H50	3.356821	6.258680
Tetratriacontane-C34H70	2.359850	5.156380
Octacosane-C28H58	1.985621	2.356450
1-Pentene, 3-methyl-C6H12	15.7908	27.23022
Pentane, 3-methyl	20.50433	34.05188
4-Methyldocosane C23H48	9.90565	16.80349
1-Docosene	1.737667	2.957531

Table (2). Results of the chemical tests conducted on the soil samples collected at Gas Station (2) at 4.0 and 6.0 m depths.

Test Parameters	% of hydrocarbons by Wt of Soil Samples	
	BH-01 Depth 4.0 m	BH-02 Depth 6.0 m
Dodecane $$ n-Dodecane-C12H26	0.586319	0.977198
Tridecane C13H28	1.316936	2.194893
Tetradecane-C14H30	3.201052	5.335087
Pentadecane-C15H32	4.45537	7.42561
Heptadecane-C17H36	5.309717	8.849528
Heneicosane-C21H44	2.169556	3.615927
Heptadecane-C17H46	6.58337	10.97228
Heneicosane-C21H44	6.65061	11.08435
Hexadecane,2,6,10,14-tetramethyl-C20H42	2.347495	3.912491
Nonadecane-C19H40	6.69362	11.15604
Eicosane-C20H42	6.5180	10.8633
Tetracosane-C24H50	5.728577	9.547628
Tetratriacontane-C34H70	4.879555	8.132591
Octacosane-C28H58	3.55985	5.93308
1-Pentene, 3-methyl-C6H12	10.32212	19.23568
Pentane, 3-methyl	15.2354	18.35682
4-Methyldocosane C23H48	8.02563	12.3568
1-Docosene	1.65863	1.89654

3.3 Discussion

The results of the chemical analysis as shown in Tables (1) and (2) show that there is a serious problem that needs to be looked at. The concentrations of the hydrocarbons exist in the collected soil samples poses environmental threats to people living near-by the investigated gas stations. The water table couldn't be reached during the boreholes excavation and consequently there were no collected groundwater samples. The study scope did not include executing deep sampling in order to collect groundwater samples. However, increasing concentrations of hydrocarbons in the soil coupled with the high permeability nature of it would eventually lead to the development of a leaching process of contaminants to reach the groundwater aquifer in the area.

4. Conclusions

The current study focused on the environmental threats of leaking underground fuel tanks of aged gas stations in the City of Buraidiah, AlQassim, Saudi Arabia. Two sites were selected among the oldest constructed gas stations in the city where a geoenvironmental investigation was launched. The investigation showed that the soil profile at these sites is high permeable meaning that any fuel leakage would transport easily through soil layers. The study also showed that there is an actual environmental problem in the investigated sites that requires authorities' attention. The soil at the two sites has high flammable solvents contents and high concentration percentages of hydrocarbons compounds. The hydrocarbon compounds constitute an environmental hazardous problem for the area that must be thoroughly cured. Published research shows that launching a remediation process in the contaminated sites could reverse the contamination hazardous effect. The remediation process is also essential in order to stop propagation of the environmental threat. Although the current study did not elaborate on the status of the groundwater aquifer in the area; the literature review shows that most likely the soil contamination would eventually led to groundwater contamination as well; if it has not already done so. Therefore, it is highly recommended to launch a process of surveying other potential contaminated sites in the city and a remediation process for cleaning the contaminated sites. Generally speaking, USEPA suggests several techniques to be used for detecting leakage from UFT such as; automatic tank gauging systems and statistical inventory reconciliation which monitors the fuel consumption on monthly bases. These are just preliminary recommendations which should be considered by authorities until the necessary regulations for constructing the UFT are updated and set according to the world wide standards.

5. Acknowledgement

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