The integration of space born and ground remotely sensed data in exploring the environmental stresses and deterioration in Ras-Gharib area, Gulf of Suez, Egypt

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Abstract:

Different remotely sensed techniques were used in an integrated way for studying the factors affecting the deterioration of the environmental parameters for area subjected to different natural and man made stresses. These remotely sensed data include: satellite data of Landsat Enhanced Thematic Mapper (ETM+), Space Shuttle data of Shuttle Radar Topography Mission (SRTM), and data from ground subsurface geo-electrical investigation. This study was applied on a coastal area that includes oil exploration and production activities.Throuout the years the area was subjected to different environmental stresses that led to environmental deterioration of its physical and biological parameters.

The satellite imageries were used to identify changes happened in the land cover and land-use classes including change in the size of water bodies, sabkhas, vegetation cover disappear and crude oil leakage as a point contamination source.

The SRTM data was used to build the DEM and the terrain characteristics for the area including surface topographic properties and surface water and contamination regime.

Based on the findings of a geo-electric survey (using Schlumberger Geo-electric Sounding) the ground surface water level was measured and the presence of fresh, brackish or salt water was identified.
A field investigation was conducted and the surface and ground water contaminations was monitored and measured. Air pollutions and noise was also measured and identified.
All these different environmental parameters as a result of the oil industry were identified and hot spots that subjected to environmental deterioration were pointed out for immediate environmental actions and measures.
Geographic Information System (GIS) was used to include all these data layers as an active database for the area for the purpose of identifying hot spots and prioritizing locations based on their environmental conditions as well as for monitoring plans.

Key words:
Landsat ETM+, SRTM, land cover, terrain characteristics, surface water regime, geo-electrical investigation, GIS, Ras-Ghareb, Egypt

1. Assessment Methodology

1.1 Approach

1.1.1 Remote Sensing

Satellite images were obtained and analyzed to get acquainted with the drainage basins, flood routes and general ecology of the area.

Two different types of remotely sensed data were used for the production of the physical environment baseline maps:

- A Shuttle Radar Topography Mission Scene (SRTM) of a resolution of 3 Arc. Second was used to produce all the terrain characteristics maps.
- Two Landsat Scenes were used to conduct this study. The first is a TM image acquired on 1984 while the second is an ETM+ acquired on 2000.

Data processing was carried out using two powerful wide-spread software:

- ERDAS IMAGINE Version 8.7 for remotely sensed data processing.
- ARC/GIS Version 9.0 for Geographic Information Systems.

Using different satellite data, field studies, measurements and verifications, different thematic maps for the physical environment baseline were produced.

1.1.2 Geophysical Survey

The geophysical survey comprised electrical exploration of the geological and hydrogeological features of the area. The survey dealt with the electrical state of the earth and provided conclusions concerning the electrical properties of rocks and minerals under different geological environments, as well as their influences upon various geological phenomena.

The resistivity method was carried out using Schlumberger configuration (vertical electrical sounding) to detect the subsurface geologic sections and to determine the thickness of the different lithologic layers through the subsurface sections. In this method, an electric current (a direct or very low frequency alternating current) is introduced into the ground by two or more electrodes and the potential difference is measured between two points (probes) suitably chosen with respect to the current electrodes. The potential difference for a unit current sent through the ground is a measure of electrical resistance of the ground between the probes (Battacharya and Patra, 1968).

More details about the application of the method and interpretation of data are presented in Annex 2.

1.1.3 Surface Water Sampling

Six locations were identified in the exposed surface waters and salt marshes of Area "A". Samples were collected for laboratory analysis. The objective of the sampling exercise was to acquire quantifiable characterization of the surface water quality and to assess the impacts, in relation to Area "A" operations.

Grab samples were collected from the six locations on 17th of April and were transported to laboratory on the same day for analysis. The samples were analyzed for chemical parameters (COD, TDS, TKN, oil and grease, H_2S, heavy metals, TOC, and BTEX).

1.1.4 Groundwater and Soil Sampling

Groundwater level and flow characteristics were assessed by the geophysical survey as mentioned in Section 2.1.4. According to the basins of the area, slopes and aspect, 15 locations were identified for drilling groundwater monitoring wells. These 15 locations were selected to detect the fate of spills resulting from the activities at the four oil fields.

Four other locations were identified for drilling boreholes and collecting soil samples. The objectives of the boreholes were to identify the depth of soil impacted by oil spills from storage tanks in block stations. Furthermore, four other locations were selected for excavating trial pits in order to take shallow soil samples from certain areas.

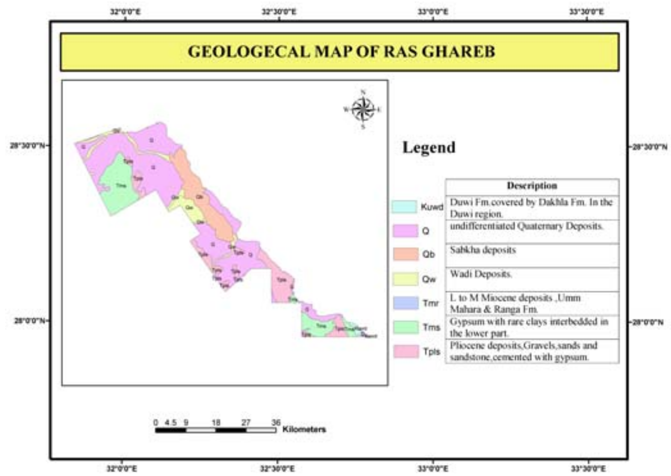
2. Description of the Environment

2.1 Geology and Hydrogeology

2.1.1 Regional Geology

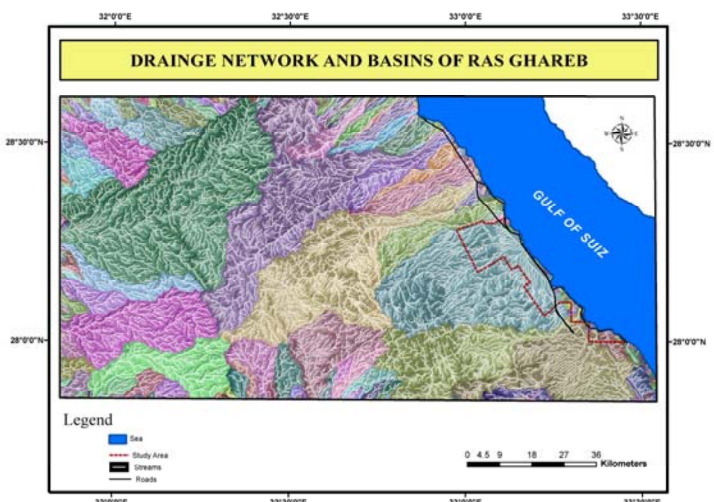
The studied area is composed of three main geomorphic units; namely from west to east: (1) mountain terrain, (2) pediment, and (3) coastal plain.

The mountain terrain occupies an area twice that of the low-lying terrain (including pediment and coastal plain). It is built up of high altitudes, up to 1745 m ASL (Gabal Gharib), more or less coherently trending parallel to the coast and interrupted by a number of detached masses and peaks. It is composed essentially of crystalline Precambrain rocks, dominated by Granitoid rocks and Metavolcanics, and subordinate upper Cretaceous sedimentary succession. On the other hand, the low-lying terrain is gently sloping and is covered mainly by Quaternary deposits and less dominantly by low-lying beds of upper Cretaceous, Miocene and Pliocene sedimentary units. The boundary between mountains and low-lying terrain is distinct and runs commonly along NNW-SSE trending normal faults. Fractures (including faults and joints) are the dominant structural elements present. The density and persistence of the mapped fractures are variable. They attain different extensions and directions, and strike mainly NE (N30-40E), NNW (N20-30W) or NNE (N10-20E).



2.1.2 Drainage Network

The drainage network of the Ras Gharib area (Figure 4-3), as a whole, is external, well-developed, highly integrated, variably dense, and partially affected by the structural grain of the district.



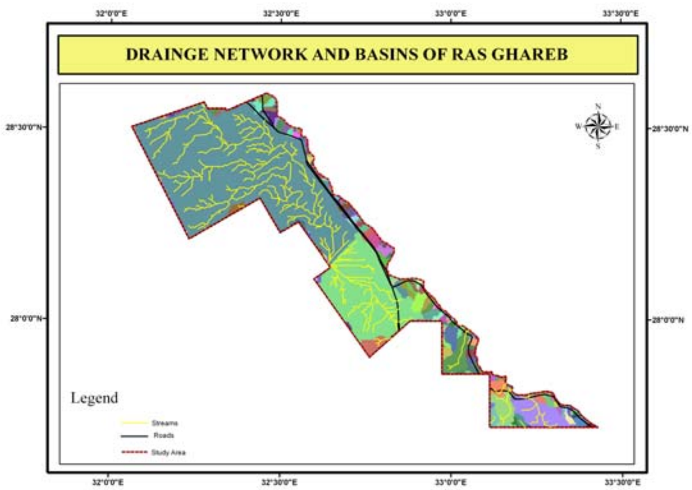
The drainage system, dissecting the mountainous terrain, is narrow, persistent, deep, and steep sided, highly integrated and ramified. It is dominated by dendritic and trellis patterns. Faults and fractures control large parts of the main streams and their tributaries. On the other hand, the drainage system, crossing the peneplained terrain, is wide, shallow and tributaries are rather long. It is arranged in parallel, braided and dichotomic fashions.

The drainage network of the study area is composed principally of a number of large hydrographic basins.

Wadi tributary maps of different orders show that:

(1) The characteristics and patterns of wadis draining the mountainous terrain differ grossly from those draining the low-lying terrain,
(2) Low order wadis in the mountainous terrain are relatively short and partly oriented due to structural and/ lithological control.

The Quaternary fluviatile deposits map indicates that:
(1) The fluviatile deposits occupy more than 50% of the total area, which are suitable for grazing after rainfall,
(2) The fluvial plains attain different forms (linear and irregular), widths, orientations, angles of junction and angularity,
(3) The wide alluvial plains present in the mountainous terrain probably represent shallow basins or old dry lakes (local base levels), which are mostly suitable to act as unconfined shallow groundwater reservoirs, and
(4) Large segments of the alluvial plains, particularly those in the crystalline basement rocks are linear and mostly guided by fractures and faults. Such segments are forecasted as suitable zones for shallow groundwater, particularly at fault intersections.

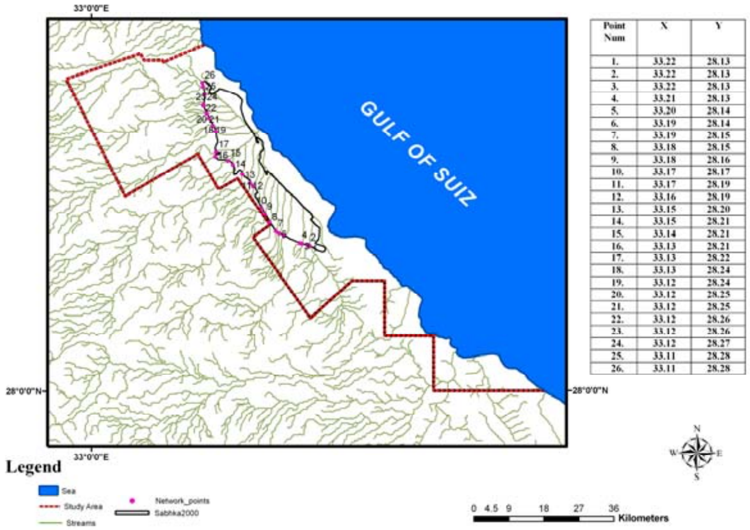


2.1.3 Hydro-Morphometric Analysis

The geo-morphological parameters of the basins and the hydro-morphometric analysis of these data indicate that these basins are of high flooding probability and low groundwater potential. It means that the effect of surface, or near surface, runoff is higher than that of groundwater in terms of point contamination from oil surface leakage allover the area.

Flash flood-vulnerable sites along the boundary of the Area "A" are identified and pointed out in Figure 4-4.

INTERSECTION OF DRAINAGE WITH SUBKHA

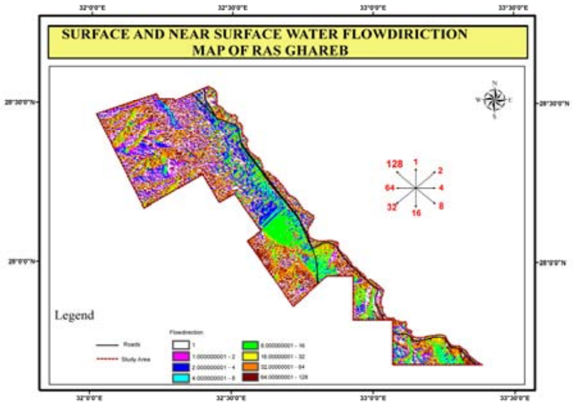


Point Num	X	Y
1.	33.22	28.13
2.	33.22	28.13
3.	33.22	28.13
4.	33.21	28.13
5.	33.20	28.14
6.	33.19	28.14
7.	33.19	28.15
8.	33.18	28.15
9.	33.18	28.16
10.	33.17	28.17
11.	33.17	28.19
12.	33.16	28.19
13.	33.15	28.20
14.	33.15	28.21
15.	33.14	28.21
16.	33.13	28.21
17.	33.13	28.22
18.	33.13	28.24
19.	33.12	28.24
20.	33.12	28.25
21.	33.12	28.25
22.	33.12	28.26
23.	33.12	28.26
24.	33.12	28.27
25.	33.11	28.28
26.	33.11	28.28

2.1.4 Groundwater

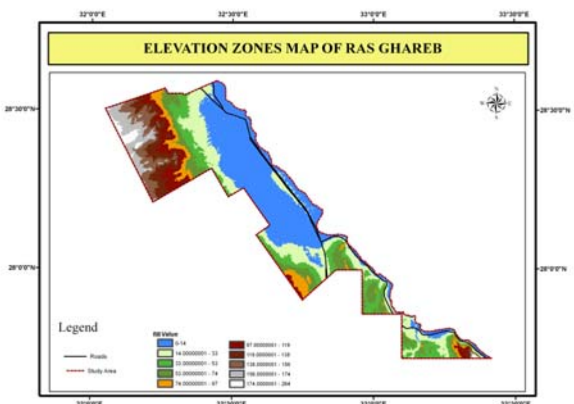
The alluvium deposits in Ras Gharib-Ras Gemsa represent an insignificant water bearing formation, which is locally detected, in the coastal plain, e.g. Ras Gharib area. It is lithologically composed of coarse to very coarse sand and gravel with minor clay streaks. The thickness varies from few meters to about 200m (Gharib area). Generally, this thickness increases towards the Gulf of Suez. The water salinity of the alluvium aquifer ranges around 8.36 g/l (Gharib costal-western well). Generally, the salinity (mainly sodium chloride) of the water increases towards the Gulf of Suez, this is due to seawater intrusion, as well as the leaching processes. According to the results of the geophysical survey carried out at Area "A", the following was concluded:

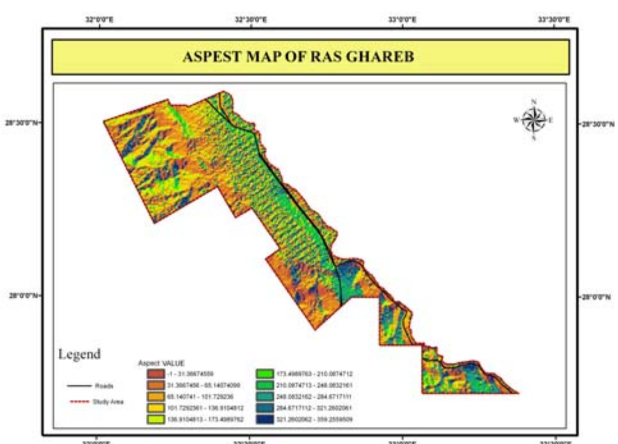
- The study area consists of several units, including a surface layer of high receptivity values. A polluted water zone exhibiting different thicknesses also exists. The polluted water zone is saturated with surface waters resulting from Area "A" operations.
- A sea water saturated zone exists at different depths and reflects very low receptivity values.
- Yosr and Shokeir Oil Fields are characterized by the presence of Sabkha layer (high gypsum and Halite soil)
- The groundwater saturated zone exists at a depth ranging from 5 to 22 meters

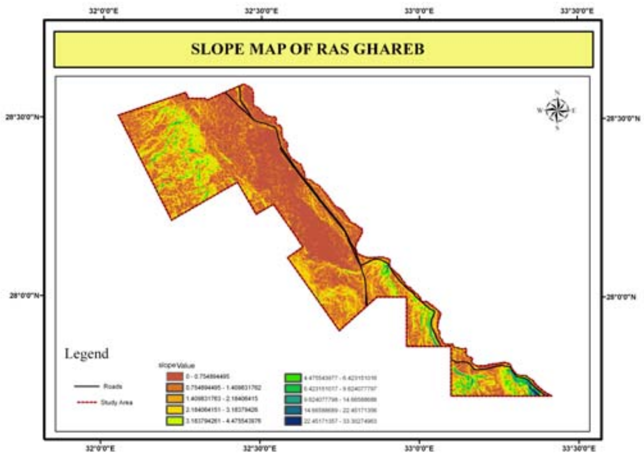


2.2 Surface Water

Surface topography:
The surface topography was studied using SRTM DEM and ARC/GIS software to create different maps including elevation zones, aspect and slope maps Figures ( ).



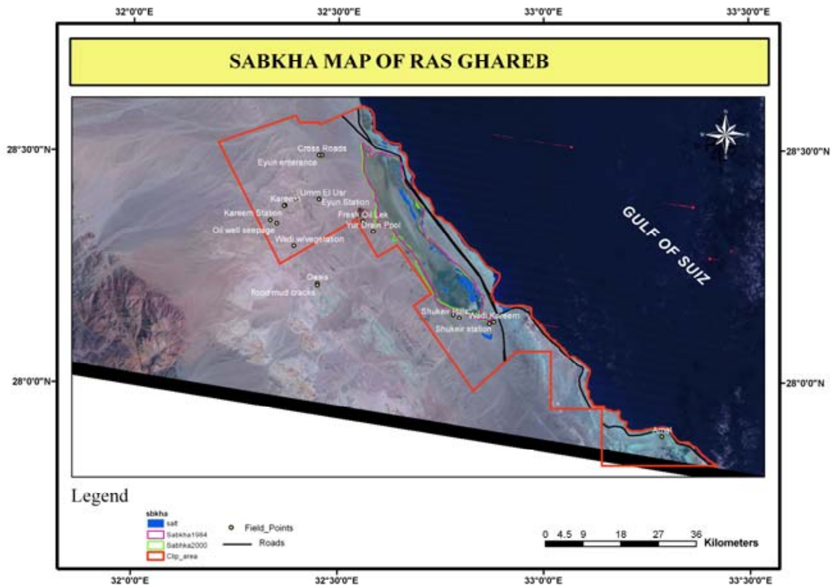




A surface water body, existing within Area "A", is composed of a large salt marsh or "Sabkha". Parts of the sabkha are exposed (surface water lakes), while other parts are composed of shallow subsurface water (from 0.1 to 0.5 meters deep). The exposed surface water portion of the sabkha varies according to variation in water table.

The largest exposed surface water area (lake) of the Sabkha is located in the southern part of Area "A" (Shokeir field). The lake extends from near well Shokeir 8 up to a few kilometers to the northwest. Smaller sabkha lakes exist in different parts, from the eastern side (near the coastal road) to the western side (near the internal main road connecting Area "A" fields). The sabkha also includes salt concentration ponds, located between Um El Yosr and Shokeir fields. Photos 4-1 to 4-4 illustrate different parts of the sabkha.

The Sabkha occupies an area of about 57 km^2. The area of the sabkha has increased in the past 20 years. Figure 4-5 illustrates the increase in sabkha area, which was estimated through digitizing and comparing a satellite image taken in 1984 with another one taken in year 2000. This increase, estimated as approximately 0.3 km^2, mainly took place in the northern part near Um El Yusr block station.



The increase of sabkha area in the northern part is probably related to the discharge of produced water from Um El Yosr block station. The water is discharged to two large evaporation ponds (in series), to be finally dissipated to the sabkha. The physical nature and water quality were obviously affected by the discharges. Stretches of produced water with obvious oil contamination were detected in wide areas of the sabkha near Um El Yosr (Photos 4-5 and 46).

2.3 Groundwater Contamination

Features of the groundwater aquifers and drainage systems were determined through examining satellite images as well as through conducting a geophysical (geoelectric) survey. The survey concluded that depths to groundwater saturated zones in the four fields. Hydro-morphometric analysis indicated that pollutant transport in the area follows a horizontal surface, or near surface, runoff pattern rather than a vertical leaching pattern. As such, lower elevation areas in the drainage network are more subject to groundwater pollution impact resulting from spills. This particularly applies to the points where drainage lines intersect with the sabkha. Accordingly, 15 locations for establishing groundwater monitoring wells were identified around Area "A", where spills are likely to be detected. Some locations were selected in highlands in order to detect water quality variation with land altitude. Figure 5-6 presents the proposed locations of the monitoring wells.

2.3.1 Groundwater

-The results of the geophysical survey showed that the depth to the groundwater saturated

zone varies between 5 meters to 25 meters.
-Hydro-morphometric analysis indicated that pollutant transport in the area is taking horizontal surface, or near surface, runoff pattern rather than a vertical leaching pattern. Therefore, the locations where groundwater quality is most liable to be impacted by spills are at the intersections of the drainage lines with the sabkha body.

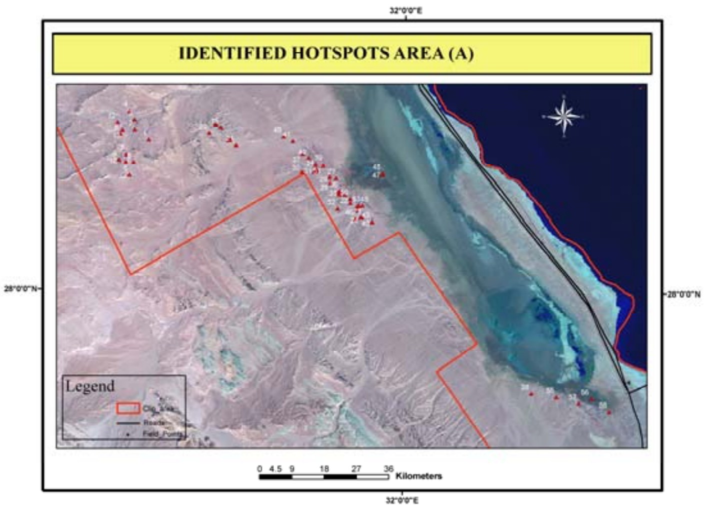
2.4. Results of the quantitative interpretation

The thirty vertical electrical sounding stations of the studied area are interpreted in terms of actual receptivity and depths for the encountered layers constituting the shallow section of the study area. This interpretation is carried out by using manual interpretation as an initial model for Sclumberger and IPI2win program. Accordingly, the varieties of limestone, which reflect higher values of resistivities, while. Groundwater saturated zone exhibit lower resistivity values. .Moreover, the sea water saturated zones reflect very low resistivity values. The interpretation of the vertical electrical sounding curves reveals that, the number of interpreted layers is ranged between four and seven layers. Also, the true resistivity values are carried from 0.1 to 25000 ohm.m. Added, the thicknesses of these layers are ranged from 0.225 to 122 m, as shown in Figures of the VES interpretation . The final result of the interpretation of the VES curves indicate that the study area consist of different layers such as surface layer of high resistivity values, polluted water saturated zone, groundwater saturated zone and sea water saturated zone can be indicated as follows:

1. The study area consists of several units such as surface layer of high receptivity values, the polluted water zone which saturated from the surface water from the processing stations, which exhibit different thicknesses.
2. Sea water saturated zone at different depths and reflect very low receptivity values.
3. Groundwater saturated zone at depth ranged from 5 to 22 meters.
4. Yusr and Shukeir Oil Fields characterized by the presence of Sabkha layer (high gypsum and Halite soil)
5. Dry zone, which show high receptivity values.
6. At kareem Oil Field the depth of the test wells must ranged from 10 to 15m.

7. At Ayun Oil Field the depth of the test wells must ranged from 20 to 25m.
8. At yusr Oil Field the depth of the test wells must ranged from 10 to 15m.
9. At Shukeir Oil Field the depth of the test wells must ranged from 5 to 10m.

The study identified the major potential sources of contamination and mapped hot-spot areas Figure (), where visible contamination was detected.



Based on the findings of a geoelectric survey (using Schlumberger Geoelectric Sounding), the study identified 15 locations for collection of groundwater samples for analyses in order to reflect the state of groundwater contamination. Groundwater sampling and analyses was completed following the submission of the report. Accordingly, this addendum was prepared to present and discuss these findings.

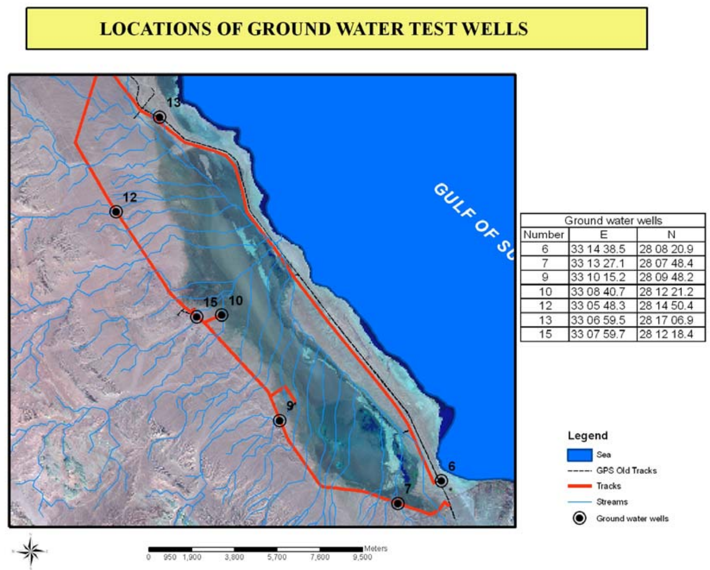
2.1 Selection of Groundwater Monitoring Locations

The study area generally comprises several layers, including; a surface layer; a polluted water zone exhibiting different thickness, which is saturated with surface waters resulting from Area "A" operations; a sea water saturated zone at different depths; and, a Sabkha layer (high gypsum and Halite soil) characterizing Yosr and Shokeir Oil Fields. The groundwater saturated zone exists at a depth ranging from 5 to 22 meters as follows:

- Dry zone.
- Groundwater depth ranging from 10 to15m (Kareem Oil Field).
- Groundwater depth ranging from 20 to 25m (Ayoun Oil Field).
- Groundwater depth ranging from 10 to 15m (Yosr Oil Field).
- Groundwater depth ranging from 5 to 10m (Shokeir Oil Field).

The geo-morphological parameters of the drainage basins and the hydro-morphometric analysis carried out in the baseline study indicated that the basins are of high flooding probability and low groundwater potential. This means that the effect of surface or near surface, runoff is higher than that of groundwater in terms of point contamination from oil surface leakage allover the area. In other words, the pollutant transport in the area is following a horizontal surface, or near surface, runoff pattern rather than a vertical leaching pattern.

Accordingly, the areas where maximum effect on groundwater quality, as result of pollutants spills in the area, are the low elevation areas within drainage network. This particularly applies to the points where drainage lines intersect with the sabkha. 15 locations were identified, using Geographic Information System (GIS), for groundwater analyses at these intersections to reflect the fate of spills resulting from the activities at the four oil fields. The selected locations were then prioritized, where seven locations were finally selected.



Ground water wells		
Number	E	N
6	33 14 38.5	28 08 20.9
7	33 13 27.1	28 07 48.4
9	33 10 15.2	28 09 48.2
10	33 08 40.7	28 12 21.2
12	33 05 48.3	28 14 50.4
13	33 06 59.5	28 17 06.9
15	33 07 59.7	28 12 18.4

Figure: Groundwater monitoring locations

2.2 Well Preparation and Sample Collection

Monitoring wells were developed in accordance to ASTM standards. The wells were of 4” diameter and approximately 20 m in depth, within the subsurface saturated zone. No drilling fluids were used except for tap water and no fueling or lubricating of machinery was undertaken on sampling sites.

Wells were purged for 5 well volumes, requiring approximately 12 hours at 4 bars. Samples were collected by the laboratory technician and were stored in suitable containers, preserved in cool boxes at 4°C, and dispatched to the laboratory.

3. Results of Groundwater Sample Analyses

Table 1 below provides the results of the groundwater analyses. The table also provides Dutch threshold limits indicating the necessity for remedial action as follows:

Table 1: Groundwater Analyses Results

Parameters	Unit	Well Numbers							Intervention Values (Dutch standards)[1]
		10	12	15	6	7	9	13	
Water Temperature	◦C	22	22	22	22	22	22	22	-
pH	-	7.2	7.4	7.5	7.8	7.6	7.8	7.8	-
Electrical Conductivity	μmho/cm	62000	77000	43000	50000	18000	31000	46000	-
BTEX (Total BTEX)	μg/l	ND	0.041	0.092	ND	0.049	ND	ND	
Benzene	μg/l								30
Toluene	μg/l								1000
Ethyle Benzene	μg/l								150
Xylene	μg/l								70
Total Petroleum Hydrocarbons	μg/l	173	114	169	10	24	126	163	Site specific
Iron	mg/l	5.8	6.1	6.0	5.5	6.2	6.1	5.6	
Manganese	mg/l	ND	ND	ND	ND	ND	ND	ND	
Copper	mg/l	0.071	0.069	0.08	0.076	0.082	0.077	0.074	0.075
Zinc	mg/l	0.198	0.182	0.211	0.175	0.201	0.177	0.164	0.8
Lead	mg/l	0.92	1.32	1.45	1.53	1.11	1.08	1.16	0.075
Cadmium	mg/l	0.085	0.093	0.09	0.089	0.078	0.082	0.091	0.006
Chromium	mg/l	0.018	0.022	0.023	ND	0.016	0.02	ND	0.03
Selenium	mg/l	ND	ND	ND	ND	ND	ND	ND	0.16
Arsenic	mg/l	ND	ND	ND	ND	ND	ND	ND	0.06
Cyanide	mg/l	ND	ND	ND	ND	ND	ND	ND	1.5
Mercury	μg/l	ND	ND	ND	ND	ND	ND	ND	0.3

Notes: 1) Intervention values represent serious contamination 2) Detection limits in all heavy metals, except for mercury are 0.005 mg/l 3) Detection limits for mercury measurements are 0.05 μg/l

3.1 TPH and BTEX (Benzene, Toluene, Ethyle Benzene and Xylene)

Total petroleum hydrocarbons were measured to determine the concentration of petroleum in the soil. The results indicated the existence of low levels of TPH in the groundwater. BTEX, were also measured in the groundwater. The total measured BTEX levels were found lower than the intervention values of any of its individual components (Benzene,Toluene,EthyleBenzeneorXylene)

3.2 Heavy Metals

Zinc, chromium, selenium, arsenic, cyanide and mercury were found below the intervention values. Copper levels were found around the intervention values, whereas lead and cadmium are above the intervention values

4. Analysis of Results

In general, the results of the groundwater analyses were found consistent throughout the sampled locations, values exceeded the intervention levels for lead and cadmium in all the samples. However, highest levels of cadmium were found near Karim and Ayoun.

Groundwater analyses results also showed that the highest levels of BTEX and TPH were detected at well numbers 10 and 15 respectively, which are downstream Um El Yosr station.

It is expected that the high levels recorded at point 9 resulted from surface leakage (almost continuous) from the pipelines linking the oil fields to Shukeir station. This area is of lower altitude in comparison to the surroundings, which creates higher pressure on the pipelines, making it of more potential to leak.

Crude oil is generally composed of a wide range of hydrocarbons and a small amount of impurities. The composition of the crude varies significantly according to its source. Crude may also include different types of heavy metals including arsenic, cadmium, mercury and nickel. However, analyses of the crude oil produced in the area are unavailable. Moreover, the produced water during exploration and production activities could generally be a source of brine, petroleum hydrocarbons, natural radioactivity and heavy metals. Leaks, spills and releases of this water may contaminate both soil and groundwater. Heavy metals could also result from additives used in petroleum activities, disposal of drilling muds, disposal of batteries, transformers, etc.

Surface transport of petroleum wastes generally occurs when large amounts are discharged onto ground, especially in the existence of storm water runoff. Hydrocarbons move with surface runoff as they are lighter than water. Subsurface transport could occur above the water table or through the geologic formations (especially when abandoned wells are improperly plugged), where hydrocarbons, salt and heavy metals may flow into formations that contain fresh water.

In conclusion, the investigations proved that there has been a detectable negative impact on the groundwater quality. It is difficult to relate the contribution of each activity in the area to this impact. However, and as mentioned earlier, it is expected that the pollutants were transported, from their potential sources (production and other activities in the area), through surface and near surface runoff towards the lower elevation areas, which were selected for groundwater analyses. Figure 2 relates each monitoring location to its potential contamination source (represented in different colors) in the upstream area.

Currently, groundwater is of no use in the area as it is of high salinity. Surface water appears to be healthy, with the exception of the northern parts of the sabkha and other locations upstream operations in wells and block stations. The survey team could see fish living in these waters. It is expected that if the sources of pollution in the area are cleaned and discontinued, the quality of both surface and groundwater would improve with time.

Environmental Baseline Survey – Area "A" (Addendum)

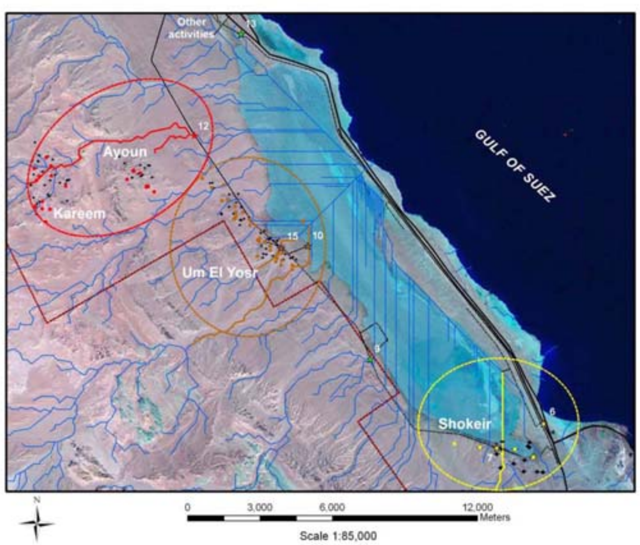


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Figure 2: Monitoring Points and their Relation to Identified Hotspots as well as their Relation to Oil and Other Activities