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LITTORAL POLLUTION ALONG THE COAST OF SAUDI ARABIA

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Saudi Arabia occupies the major portion of the Arabian Peninsula with a coastline that exceeds 3500km. More than 2400km of this coast extends along the Red Sea and the rest is on the Arabian Gulf. Along these coasts, concentrated human activities occur, especially those related to oil, power and desalination activities, and other industrial and development efforts. These activities cause littoral pollution in seawater, which impacts the marine environment and man's well being. The major pollutants are sewage outfalls, oil and chemical plumes, thermal waters, and sediment transport. This environmental condition is being examined and environmental legislation is being considered by several ministries in Saudi Arabia. The lack of credible studies makes the status quo unclear to decision makers. It is difficult to make the appropriate decisions and apply required changes. This study shows examples of pollution along the Saudi coast. New techniques were valuable, notably the use of satellite images with high resolution (IKONOS). A number of stretches were selected along the coast to identify the type, sources and flow mechanism of pollutants in the littoral zone. It is also noted that the continental shelf has a gentle slope gradient, which makes the terrestrial pollutants often settle close to the coastline which increases their harmful impact.

INTRODUCTION

The increase in human activities has obviously exacerbated environmental conditions, notably in the coastal zones, which usually have the largest urban settlements and cities with their related activities. However, this is accompanied with a miscellany of geo-environmental problems that encompass both man and nature. Aspects of solid and liquid pollution have extended to the littoral environment, which created a serious geo-environmental problem in the last few decades, and it has only increased along with the development of industrial and commercial activities in coastal zones. In some of these zones, environmental forensics is given to the terrestrial environment, since it has a direct impact on the human being, while the marine environment has seen less attention, ignoring its tight relation with human life.

During field observations along many coastlines, one can notice an obvious differentiation in the color and patterns of seawater, which is due to pollutants that either derived from land or are released directly into the sea from boats and ships. Few studies have identified the littoral pollution sources in the marine environment, and many of applied studies are concerned only with the chemical composition of seawater (e.g. salinity and other water properties), regardless of their source.

The coasts of the Arabian Peninsula encompass tremendous aspects of littoral pollution in seawater, since the region is a major source of oil production and the related activities, as well as other industrial activities such as desalination. Oil spills are known as the common littoral pollution aspects, which are widespread either directly along the coastline or at a range offshore. In this respect, awareness has increased after the Arabian Gulf War, and several workers were able to detect oil spills in 1991 (Cross 1992; Rand et al. 1992; Al-Ghunaim et al. 1992; Al-Hinai 1993).

The Kingdom of Saudi Arabia, the major territory of the Arabian Peninsula, is a typical example of several aspects of littoral pollution in seawater. The kingdom has a borderline totaling about 6760km, and approximately 3500km (52%) of this border is extended along the coast, where 2400 km are to the west on the Red Sea (29° 20' 50", 34° 59' 05" & 16° 19' 20", 42° 46' 15") and the remaining 1100 km are located on the Arabian Gulf (28° 26' 25", 48° 30' 30" & 24° 10' 30", 51° 33 03") as shown in Figure 1.

The coastal region of Saudi Arabia has several developing activities, including oil production/export, giant industrial projects, trading activities and desalination and energy plants. However, these activities are linked directly with negative impacts on the environment, and thus result in a miscellany of pollution aspects that affect the marine ecology and human health as well. From a technical point of view, applied studies on the littoral pollution are rare enough to endorse the environmental degradation along the Saudi coasts in a comprehensive way. Even though there are many concerns from the decision makers in Saudi Arabia to protect littoral water and mitigate its deterioration, monitoring approaches are taken by coastal guardianships who lack to scientific and even technical understanding, and this cannot mitigate the problem, especially where identifying the unseen aspects of littoral pollution are concerned.

Recently, space techniques, and more certainly satellite remote sensing, have become an important tool in detecting and monitoring littoral pollution in seawater. Thus, visible sensors (e.g. Landsat, Aster, AVHRR and SAR imagery) have been used to detect and characterize sewage sludge, industrial wastes dumped, and oil spills into the sea. Besides, direct detection of pollutants by satellite sensors is useful for analyzing ocean processes that are influential in the fate of

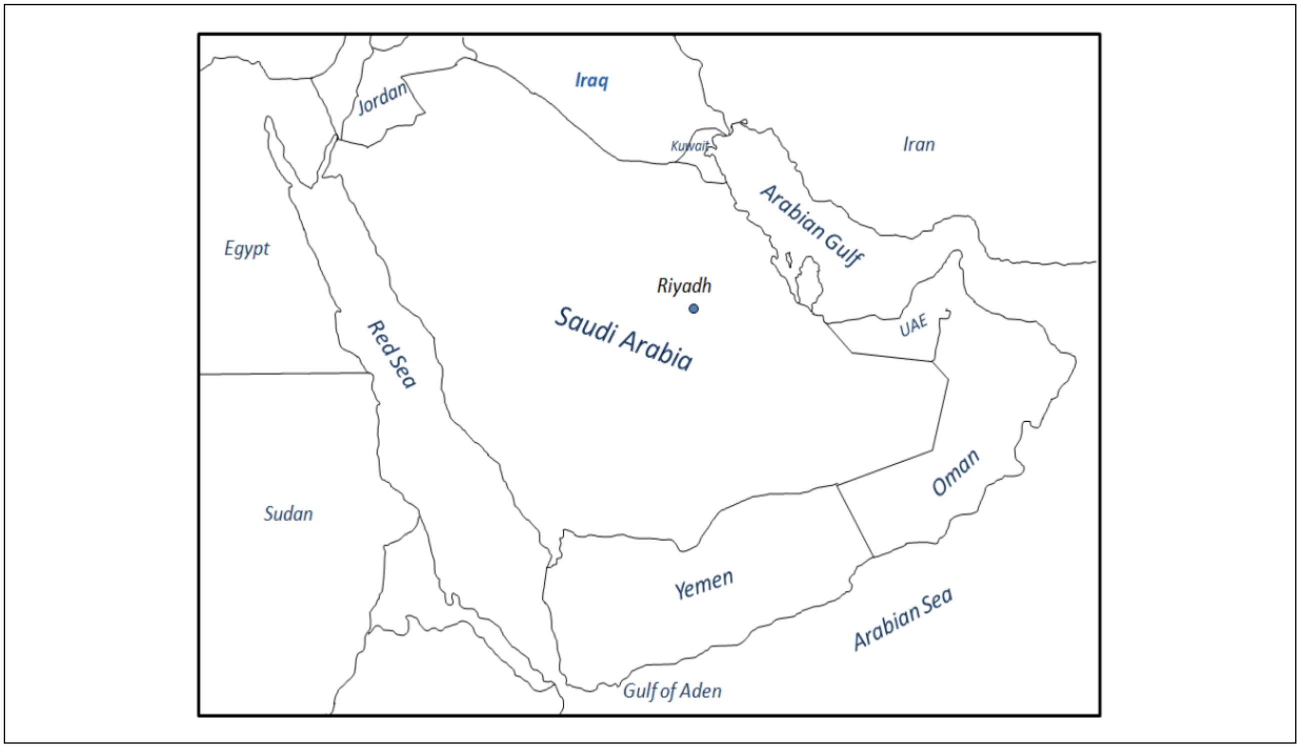

Figure 1. Location map of the Saudi Arabia and the surrounding areas.

pollutants. The rapidly accelerating interest in remote sensing for littoral pollution has resulted in the development of a diverse range of appropriate techniques, but remote sensing has yet to reach its zenith in terms of real world applications. The state of the art of remote sensing was also investigated focusing on cleaning up operations and the monitoring of the marine environment. Although there were many reports and statistics on ship accidents, causes and counter measures of the ship accidents were not sufficiently clear and effective.

This study aims to identify the existing aspects of seawater pollution along the Saudi coasts (along Red Sea and the Arabian Gulf), with a special emphasis on oil pollution, and to characterize their flow dynamics. It was applied utilizing mainly satellite images with different optical and digital advantages, which was accompanied with field assessment and other supplementary data and information. It proved to be useful as tools of analysis, since they have been applied in several coastal regions in the world and lead to detailed and valuable results, which helped put effective environmental strategies in place.

MATERIALS AND METHOD

There are several approaches of analysis to identify the littoral pollution from space. It requires, in a broad sense, satellite image processing that is followed by field verification on the hotspots identified by remote sensing tools. However, the availability of tools governs selecting the approach of investigation. Hence, remote sensing can be utilized in several applications to give obvious observation of the objects in the marine environment. In littoral pollution detection, remote sensing; however, is useful for large area surveillance (Mullin, 2006).

Using a single tool of optical remote sensing in littoral pollution detection may create erroneous results by observing false illusions; i.e. oil slick look-a-likes, reflected patterns of sea currents, etc, which give rise to invisible signals (O'Neil, 1983; Goodman, 1989 and 1992; Thornton, 1992). Therefore, studying and monitoring littoral pollution in seawater would be more realistic if various aspects of satellite images with different optical properties are used. In this study, a miscellany of satellite images was used. They were attributed to moderate and high spatial resolution. These are: ASTER and IKONOS satellite images. These images were processed using two software types specialized for image treatments. These are: ENVI-4.3 (Environment for Visualization Images), and ERDAS Imagine software. The optical and digital characteristics of these images can be summarized in Table 1. Hence, in addition to the number and characteristics of bands in each satellite image, there are also the revisit time and swath width. The first accounts for the passage time of satellite over the same region, while the swath width expresses the ground coverage of each image scene.

Table 1. Major optical and digital characteristics of these images (Abrams and Ramachandram, 2003).

Satellite	Band system	Spectral range (µm)	Spatial resolution	Bands	Revisit time	Swath width
ASTER	VNIR	0.52-0.86	15 m	1-3	16 days	60 km
	SWIR	1.60-2.430	30m	4-9		
	TIR	8.125-11.65	90m	10-14		
IKONOS	panchromatic		0.80m		3-5 days	11.3 km
	Multi-spectral	0.44-0.51	4m	1 (Blue)		
		0.50-0.59		2 Green)		
		0.63-0.69		3 (Red)		
	Pan-sharpen	0.75-0.85	1m	4 (Near IR)		

The available images are usually provided as digital data; hence they require several digital pre-processing procedures to perquisite further spatial analyses in the dedicated software. This includes, but is not limited to, atmospheric correction or normalization, image registration, geometric correction, and masking (e.g., for clouds, water, irrelevant features). These digital procedures will increase the accuracy and interpretability of the digital data during the image processing phase. In addition, image sub-setting must be applied. It includes only the part of concern from the whole image scene. The limit of study area was prepared in vector format to facilitate sub-setting of the image using Imagine software. This also has an advantage of putting fewer loads on the computer (as bytes) for further image processing steps. In addition, the selection of software counts on the resultant precision of features that exist on the processed image, and often it is utilized from more than software to process the same image.

The pre-processing digital procedures will be followed by observing objects directly on the processed image, and thus identification of littoral pollutants. This depends mainly on the visible contrast and discrimination of sea surface elements. The majority of these elements imply discrimination of: color, tone, texture, and flow pattern and temperature difference. These elements generalize the pollutant type and behavior (Shaban, 2008). Nevertheless, the identified features and terrain signatures on satellite images should be followed by field verification to confirm the obtained results from image processing.

The analysis of ASTER and IKONOS images was carried out using ERDAS Imagine software and in some instances ENVI-4.3 was utilized. Hence, special advantages were applied in each software separately. The most commonly used advantages in ERDAS Imagine are: linear histograms, directional filtering, contrasting, bands combination and sharpness. The latter, for example, reveals clear contrast in the observed images (example in Figure 2).

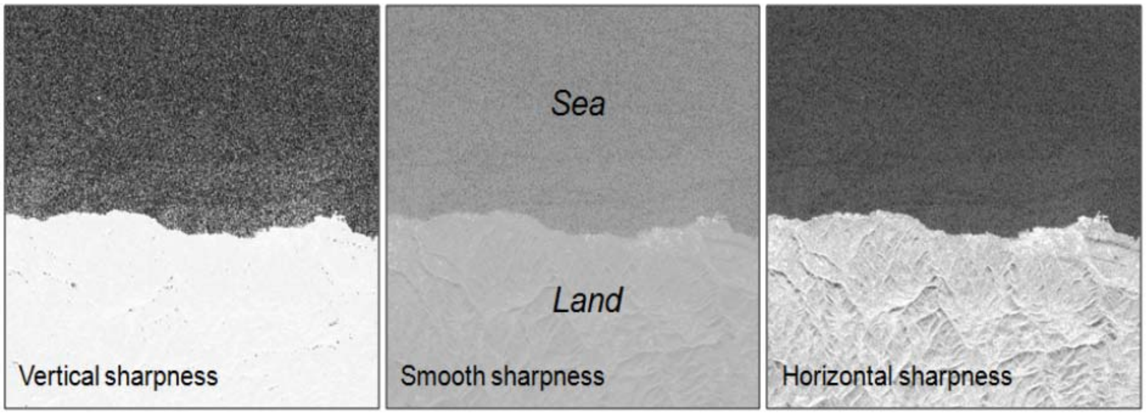

Figure 2. Different sharpness applications on *ERDAS Imagine* for the same image.

While, the major advantages used in ENVI-4.3 software were: the enhancement procedures, and more certainly the linear, Gaussian, equalization and square root applications. As well as, the interactive stretching is another application for image enhancement using contest histograms (example in Figure 3). In addition, there are various digital advantages, such as density slicing, contouring, filtering, lightening and coloring.

In combination with the above applications of image analysis; however, field verification was carried out to confirm the accuracy of image analysis. This was undertaken using GPS (Global Positioning System), in addition to the available topographic maps. Moreover, there was a recurrent filed investigation for several sites, which are dominant with pollutants. This was applied in order to monitor whether there is continuous supply of pollutants or it was just for certain period of time.

The identification of distinguished features in seawater, as observed on satellite images, depends mainly on the existing difference in the optical and digital signatures on the images, which reflects the physical property of pollutants in seawater. The major signatures for pollutants recognition in satellite images are:

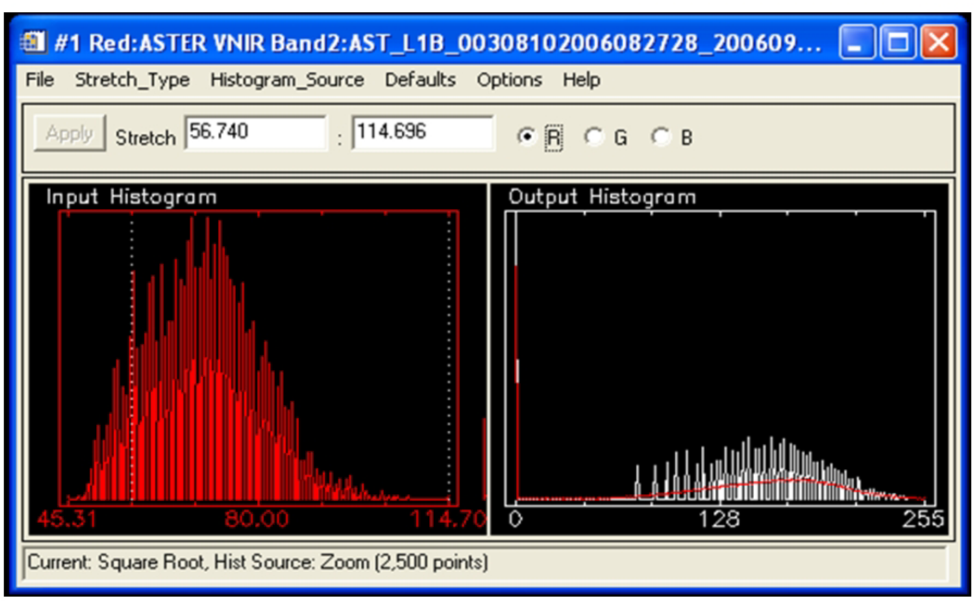

Figure 3. Example showing the use of Histograms in analyzing satellite images using ENVI-4.3.

Tone variation and color

Distinguishable variation in color/or shade from black to white creates a viewer contrast, thus features of different optical characteristics reveal different color/or tonal texture. This can be obtained applying digital advantages in ERDAS Imagine-9.1 and ENVI-4.3. Therefore, at certain time period pure seawater appears with homogenous tone starting from dark to white (Figure 2), hence any heterogeneous material (i.e. solid and liquid pollutants) with appear in different tone.

Accordingly, the color of seawater can be identified directly by visible bands on ASTER or IKONOS images. False color application can be carried out, but normal seawater remains with a unique color, while other materials will appear different from the surroundings.

Temperature difference

The temperature of seawater is usually changeable according to various physical factors, such as sun heat, wind, sea currents, depth, etc. However, the existence of any material, notably of liquid type other seawater; will be clearly distinguished through its temperature difference on satellite images. This can be applied by treating the thermal bands in the satellite image.

In this study ASTER images were useful to differentiate temperatures of the existing materials with respect to seawater, notably the ASTER sensor has four thermal infrared (TIR) bands as shown in Table 1.

Water patterns

According to the difference in the physical properties between seawater and polluted water, notably in density and chemical composition; however, pollutants floating on seawater take special patterns and configuration, which is almost controlled by its density and the existing currents and sometime wind velocity and direction (Grau & Giralt, 1990). This, in turn, permits discriminating polluted water from the normal seawater (Shaban, 2008). For example, oil spill disperses in the water as fine droplets that can be transported over large distances away from the place of the spill (Patin, 2006).

Water texture

Texture in image is attributed to the arrangement of and frequency of tonal variation in particular areas of an image, and most of texture models are based on grey-level images. It is a function of spatial uniformity of scene targets. It may be described as fine, medium, or coarse and stippled or mottled and a specific range can be obtained between black and white color variations. Rough textures would consist of a mottled tone where the grey levels change abruptly in a small area, whereas smooth textures would have very little tonal variation.

RESULTS

Having applied the above mentioned systematic procedures on satellite images considering available technical applications and concepts of image analysis; however, observations of several distinguished features in seawater were seen in different coastal regions along the Saudi littoral zones. The discrimination of the observed features was obtained following the elements of recognition as described in the previous sections. Thus, various aspects of pollutants were identified, and they were characterized by different configurations, floating behavior and scale. In addition, many of the identified pollution sources are dynamic with a continuous movement, which is controlled largely by seawater currents and wind direction.

The pollution sources are found to be concentrated mainly along the major ports, as well as at desalination and power plants. In this respect, the Kingdom of Saudi Arabia has eight major ports along the Saudi coastal zones. These are named as: Islamic port of Jeddah, King Abdul-Aziz in Dammam, King Fahed Industrial port in Al-Joubeil, King Fahed Industrial port in Yanboua, Commercial port of Al-Joubeil, Jizan port and Commercial port of Yanboua. In addition, the sixteen desalination planets, thirteen of them are located on the western coast.

There are three major existing aspects of littoral pollution along the Saudi coasts. These are, in a priority order: oil slicks, hot water and turbid water. In addition, there are several aspects of other pollution sources such as solid wastes (i.e. landfills of relatively small-scale), wastewater and sewage effluents, as well as some chemical outfalls.

Oil slicks

There are tremendous aspects of oil slicks and irregular spots that are distributed along the coasts of Saudi Arabia, notably beside ports. They almost occur with elongated shapes and connected bands of different aspects. The existing slicks are either found directly on the shoreline or off-shore at a distance from the coast. They are characterized by different dimensions, starting from few meters in length and reach in some places to more than several kilometers (Figures 4 and 5). The sources of these slicks are:

1. Leakage from ships and oil tankers due to the lack of maintenance.
2. Intended release of oily sludge and materials ships and oil tankers.
3. Leakage from the coastal refineries and factories.
4. Off-shore oil drilling
5. Natural oil release on Earth's surface.

The impact of oil wastes and residues in the littoral environment is well known to be harmful and dangerous. It causes direct and significant damages to different ecosystem components, such

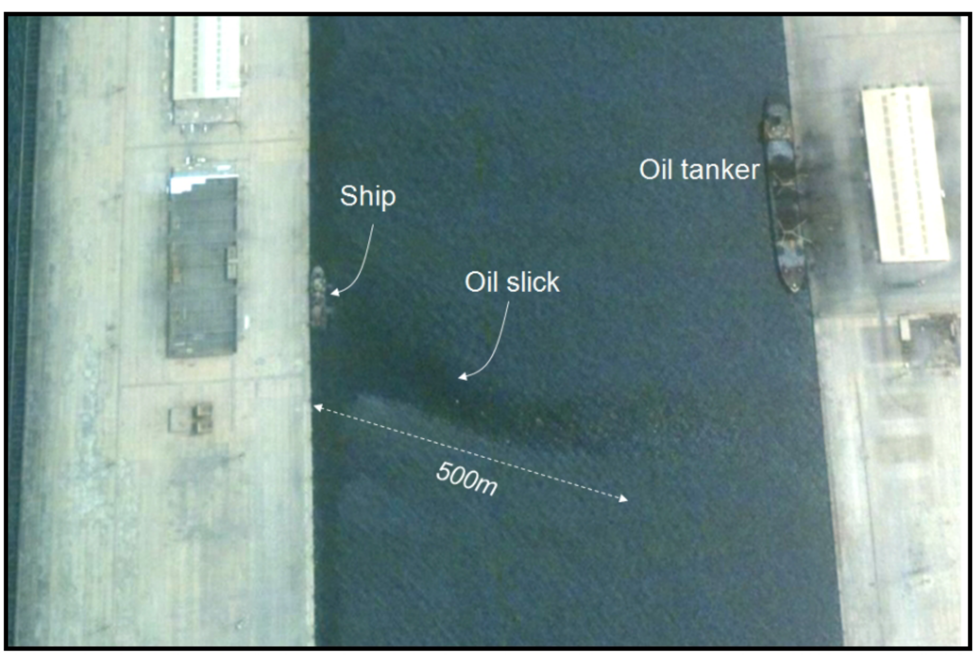

Figure 4. Oil slick released from a ship directly on the coast shelf in Jeddah port.

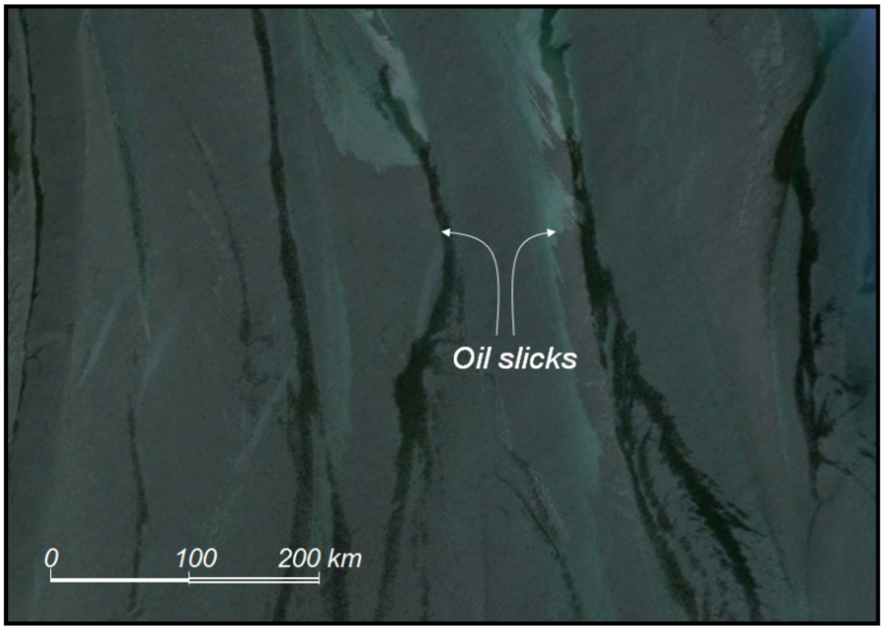

Figure 5. Oil slicks distributed off-shore near El-Khober.

as coral reefs, algal mats, mangrove and other habitats. Hence, when oil waste reaches the coast, it interacts with sediments (e.g. beach sand, gravel, rock debris, etc), vegetation, and terrestrial habitats of both wildlife and humans, causing serious contamination, which may remain for long decades. Moreover, the effects of toxic oil waste may cause mortality and contamination of fish and other food species, but long-term ecological effects may be worse.

Hot water

It is another common feature of littoral liquid pollution, which can be frequently observed along the Saudi coasts. It is attributed mainly to hot (temperature exceeding 50 °C), and sometimes warm water effluents that directed along tubes or canals from land sources directly towards the sea. The sources of hot water are the electrical power planets as well as the desalination planets, notably those operated in combination with electrical ones (Figure 6).

Even though, the spatial extents of hot water is mainly dependant on the injection energy from turbines, yet they are almost with limited dimensional aspects, which are less than few length hundreds of meters into the seawater, and usually exist as funnel-like shape. Hot water is widely distributed besides the sixteen desalination planets and the coastal power planets as well, in addition to other industrial sites, which need cooling by water in their processes..

For the hot water released from different industrial activities, including desalination and power planet source, the impact on the marine environment is almost local, but it is still harmful to the ecosystem where it is released. The influence does not restricted to the exceeding temperature of water, but also to its quality and such water is often highly contaminated with numerous aspects of pollutants, and thus it is considered as toxic water.

Turbid water

This is a widespread source of pollution, since it is common along the coasts predominant with unconsolidated and unstable rock and soil materials, and usually attributed to hydraulic erosion processes. This is well pronounced along the Saudi coasts, which are mainly encompass flat areas with loose materials, while rocky coasts are rare. Hence, sediments and loose material usually

Figure 6. Hot water effluent beside the desalination planet of Rabigh.

follow two flow mechanisms:

1. Sediments, as bed load, derived by water along streams and small-scale channels from long distance and outlets into the sea. They are usually attributed to the effect of torrential rainfall. The spatial extent of these sediments is often large and they create turbid seawater for several square kilometers into the sea.

Sediments entering seawater near the coast as an influence of natural instability of friable materials (soil and rock), especially in regions where coastal protection implements are rare. In addition, the movement of such materials can be resulted from human activities nearby the coast (excavation, construction, etc). The spatial extent of these sediments is usually restricted to the coast (few hundreds of square meters) and affected by the existing sea currents (Figure 7).

The environmental impact of sediments in the marine environment is still a matter of debate, since they are believed to have the least influence on the marine ecosystem (Nassif and Shaban, 2007). However, the pollution from sediments here is viewed from the pollutants that are derived from sediments and water from the terrestrial environment to the sea. However, large sediment loads may interrupt some flora and fauna, which are located close to the coast.

CONCLUSION AND DISCUSSION

Except the capital Riyadh, the major cities and human activities in the Kingdom of Saudi Arabia are located in the coastal zones, thus these zones are rapidly developed. The majority of these activities include oil industries and the related exporting purposes, refineries, desalination and power plants, plus many other industrial activities and factories. Thus, wastes of different aspects are thrown into the sea, as can be easily observed from field reconnaissance.

Pollution, as a geo-environmental issue, has a wide range in terms of quality and quantity, added to this the large areal extent into the littoral environment. Hence, it is not exaggeration to say that almost all the Saudi coast is polluted, with a special emphasis on areas with human activities where

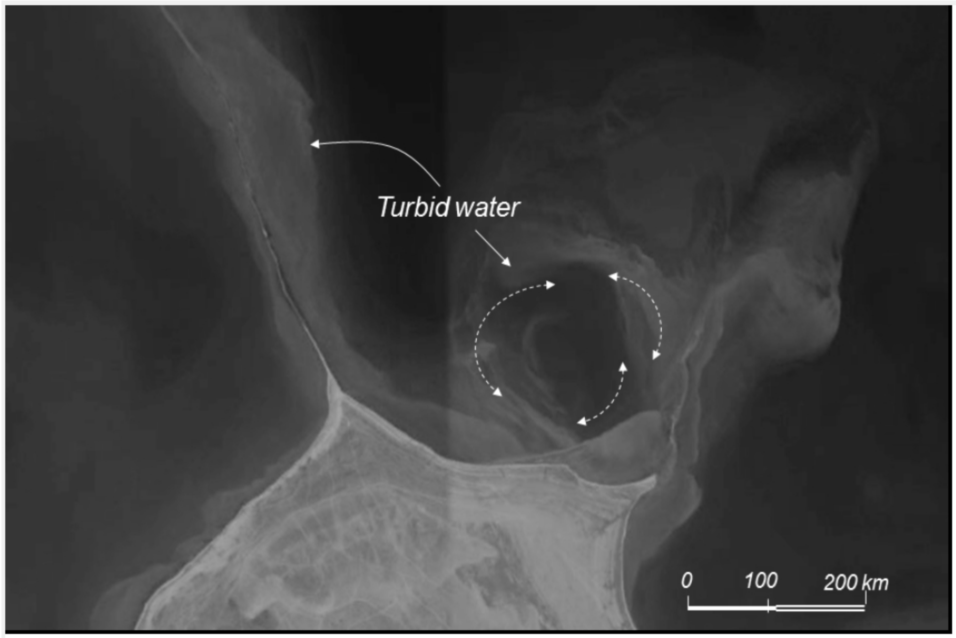

Figure 7. Turbid water affected by currents south of Al-Dhahran city.

"hotspots" exist. Among these hotspots; however, oil residues, which occur as oil slicks and dissipated patches and sometimes large spills, are the most alarming pollution aspect. The easily-motion (i.e. surface floating) of oil on sea water surface acts in pushing the off-shore slicks towards the coast, where they remain for long time harming the ecosystem.

Even though they occur with less environmental impact; however, the other two pollution aspects along the Saudi coast (hot water turbid water) have also a wide spatial distribution, notably the turbid water and sediments transport. Thus, hot water is totally damaging the ecosystem, but on the site where it directly falls. Besides, turbid water may cover several square kilometers, but with less impact. In addition, other aspects of littoral pollution are noticed, including chemicals and wastewater.

Accordingly there is a debate on the mitigation approaches of the littoral environment in Saudi Arabia. This led to many ministries to undertake this issue under their charge. These are: the Ministries of Defense and Aviation (The Organization of Forecast and Environmental Protection Research); Ministry of Foreign Affairs (National organization for Algal Life), Ministry of Agriculture (Fishery Department), as well as border guardianships. In addition, environmental legislations are being considered to protect the Saudi coasts, notably where industrial and other human activities are dominant.

Normally the assessment of littoral pollution needs a comprehensive identification tool, since it covers wide geographic areas, and because it is subjected to dynamic changes in time and space. For this reason, littoral pollution can be studied using space tools, whether satellite images or airborne surveys. This is the case in this study, which is a preliminary attempt to highlight this environmental issue. Therefore the study aims to identify the major aspects of littoral pollution along the Saudi coasts, and thus recommending the following points:

1. There must be creditable environmental legislations related to littoral pollution.
2. Mitigation implementation should be undertaken, notably along the unstable areas.
3. Quality control sites must be located along different places of the Saudi coast.

4. Increasing the number of wastewater treatment plants

5. A strategic plan must be considered for the entire Saudi coastal zone.

6. There must be an off-shore monitoring system, notably in controlling leakages from oil tankers.

7. Engineering practices should be undertaken to control the flow regime of liquid pollutants into the sea.

8. An assessment to the ecosystem should be obtained with a special regard to flora and fauna at different sites.

9. Considering coastal zones with environmental importance as natural reserves.

10. Use of space tools in identifying and control littoral pollution proved to be successful tool, thus they must be developed and given attention.

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REFERENCES

Abrams, M., and S. Ramachandra. 2003. ASTER User Handbook. Jet Propulsion laboratory, Pasadena. CA. EROS Data Center, Sioux Fall.

Al-Ghunaim, I., M. Abuzar, and F.S. Al-Qurnas. 1992. "Delineation and Monitoring of Oil Spill in the Arabian Gulf Using Landsat Thematic Mapper (TM) Data", in Proceedings of the First Thematic Conference on Remote Sensing for Marine and Coastal Environments, ERIM Conferences, Ann Arbor, Michigan, pp. 1151-1160.

Al-Hinai, K.G., M.A. Khan, A.E. Dabbagh, and T.A. Bader. 1993. "Analysis of Landsat Thematic Mapper Data for Mapping Oil Slick Concentrations - Arabian Gulf Oil Spill 1991", The Arabian Journal for Science and Engineering, Vol. 18(2), pp. 85-93.

Cross, A. 1992. "Monitoring Marine Oil Pollution Using AVHRR Data: Observations off the Coast of Kuwait and Saudi Arabia during January 1991", International Journal of Remote Sensing, Vol. 13, pp. 781-788.

Goodman, H. 1989. Application of the technology in the remote sensing of oil slicks. In: Lodge, A.E. (Ed.), John Wiley & Sons Ltd.

Goodman, H. 1992. Client needs for surveillance and tracking during oil spill. In proceedings of the first thematic conference: Remote sensing for marine and coastal environments, SPIE 1930: 69-78

Grau, C., and F. Giralt. 1990. Numerical simulation of oil spills in a generalized domain Oil & Chemical Pollution, 7, 143-159.

Mullin, J. 2006. Remote sensing and surveillance of oil spills. Project Report on: Offshore minerals Management Technology Assessment and Research. Available at: 1http://www.mms.gov/tarprojectcategories/remote.htm.

Nassif, N., and A. Shaban. 2007. Use of remote sensing to determine pollution factors, location and dynamics on the Lebanese littoral. Journal of Environmental Hydrology. Vol. 15, Paper 18.

O'Neil, R.A., R.A. Neville, and V. Thompson. 1983. The Arctic Marine Oil spill Program (AMOP) Remote Sensing Study. Environment Canada, EPS 4, EC-833, Ottawa, Ontario.

Patin, S. 2006. Environmental impact of the offshore oil and gas exploration and production. Available at: http://www.offshore-environment.com/synopsis.html

Rand, R.S., D.A. Davis, M.B. Satterwhite, and J.E. Anderson. 1992. Methods of Monitoring the Persian Gulf Oil Spill Using Digital and Hardcopy Multiband Data, U.S. Army Corps of Engineers Report, TEC-0014, 33p.

Shaban, A. 2008. Use of Satellite images to identify marine pollution along the Lebanese coast. Environmental Forensics Journal. Vol. 9: 205-214.

Thornton, D.E., M.F. Fingas, H. Whittaker, and G. Sergy. 1992. The Arctic and Marine Oil Spill Program (AMOP). Spill Technology Newsletter (Canada). 17(2): 1-20.

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