growth rate is as high as 3.3~3.4% per annum. The percentage of expatriates is almost for pure labor force which means the expatriates occupy job positions more than the Saudi nationals.

The kingdom faces a delicate problem that the Saudi economy has long needed foreign labor force to attain the dynamic development, while the increasing number of young Saudis demand their jobs. However the quick replacement of expatriates for Saudis is not an easy issue, because of the gap between the actually required position and what the young Saudis want to take.

The government of KSA has been exerting its effort to enhance the capability and efficiency to cope with the market needs with an extensive program of educations for the young Saudi nationals. The opportunity for high education to the level of university is given equally to male and female students and the number of enrolment in 1997 reached 223,802 in total, with male students of 113,774 and female 110,058. The total number in 1997 increased 50% from that in 1993 (For detail, refer to Table 2.4.3).

Table 2.4.3 Number of University Students (Enrolment)

1417/1418H* (1997)			1416H (1996)			1416/1415H (1995)		
Total	Male	Female	Total	Male	Female	Total	Male	Female
223,802	113,774	110,058	163,585	86,468	77,117	148,425	78,636	69,789

Source: Saudi Ministry of Planning (1997)

*Note: 1418H (May 7 '97~Apr.26 '98)

2.4.6 Roles of Public Organization

As seen in the section 4.2.1, the fast diversification of Saudi economy was successfully achieved. This would not be possible without the strong governmental leadership in line with the five-year plans.

Specifically the following public entities among others have contributed to the development of Saudi economy and still are pursuing their goals in the individual area.

- Saudi Arabian Oil Company (Saudi ARAMCO): Owned100 % by Saudi Government and responsible for all of the Kingdom's petroleum activities. Besides operating the Kingdom's refineries such as at Jeddah, Riyadh, Yanbu, Rabigh, Ras Tanura, following companies with foreign partners have been established or transferred from Petromin.

Saudi Aramco Mobil Refinery Co.,
Saudi Aramco Shell Refinery Co.,
Petromin Lubricating Oil Refining Co.,
Petromin Lubricating Oil Co.,

- Saudi Basic Industries Corporation (SABIC): responsible for Kingdom's industrial development utilizing the local resources of hydrocarbons and minerals as raw materials. Under the sponsorship ,some cases with partnership with foreign firms, the following companies have been established.

Steel Rolling Co.,
Saudi Iron and Steel Co.,
Saudi Methanol Co.,
Al-Jubail Fertilizer Co.,
Saudi Yanbu Petrochemical Co.,
Al-Jubail Petrochemical Co.,
Saudi Petrochemical Co.,
National Methanol Co.,
Arabian Petrochemical Co.,
Eastern Petrochemical Co.,
Saudi Arabian Fertilizer Co.,
National Plastic Co.,
National Gases Co.,
Saudi European Petrochemical Co.,
Arabian Industrial Fibers Co., etc.

- General Petroleum and Minerals Organization (PETROMIN): responsible for implementing and managing the mineral and petroleum projects. Until 1993 Petromin played the most important role in developing petroleum projects and other mining projects. In July 1993 most of petroleum related projects were transferred to Saudi Aramco.

  Petromin is now mainly responsible for all stages of mining activities. Under the sponsorship of Petromin, following companies have been established.

Saudi Arabian Mining Co.,
Arabian Drilling Co.,
Arabian Geophysical and Survey Co.,
Saudi Precious Metals Co.,

- Royal Commission of Jubail and Yanbu (RCJY): responsible for supply and management of all kinds of infra-structural services for both of the industrial cities in Al-Jubail and Yanbu.

- Saudi Consulting House (SCH): responsible for technical and consultancy services.

- Grain Silos & Flour Mills Organization (GSFMO): responsible for development of agriculture and animal husbandry.

2.4.7 Industries in Eastern Province

(1) Industries

Since 1938 when a large quantity of oil was discovered in Dammman, the Eastern Province has been the center of attractions for the government of KSA as well as for the world. As seen above, the government first exploited crude oil, and then refined it to oil products including petrochemicals and now has made a great progress of diversification of the industries through SABIC. Most of these industries are located in the Eastern Province, though Yanbu on the Red Sea side, Riyadh and other areas have been largely developed in line with the government policy of nation-wide diversification of the national economic centers. In order to facilitate the new industries, Royal Commission for Jubail and Yanbu accommodates them in its industrial cities, providing all necessary infra-structural services.

The principal industries in the Eastern Province are listed as follows:

- Refinery and NLG Plant
  Aramco refinery/NLG complex including a terminal of oil/ LNG, Ras Tanura.
  Saudi Aramco/Shell Refinery Co., Al-Jubail

- Petrochemical Plant
  Al-Jubail Petrochemical Co.,
  Eastern Petrochemical Co., Al-Jubail
  Arabian Petrochemical Co., Al-Jubail
  National Methanol Co., Al-Jubail

- Metal/Steel Plant
  Saudi Iron and Steel Co., Al-Jubail
  Zamil Steel Buildings Co. Ltd., Damman

- Chemical Fertilizer Plant
  Al-Jubail Fertilizer Co., Al-Jubail
  Saudi Arabian Fertilizer Co., Daharan

- Water Desalination and Power Generation Plant
  Saline Water Conversion Corporation, Al-Jubail
  Saudi Consolidated Electric Co., in the Eastern Province, Damman
  General Electricity Corporation

- Plastic Products Factory
  National Plastic Co., Al-Jubail
  Saudi Plastic Products Co Ltd., Damman

- Cement Plant
  Eastern Province Cement Co., Damman
  Saudi Cement Co., Damman

- Others
  National Paper Products Company-Damman, Damman
  Saudi Fisheries Co., Damman
  Arabian Geophysical and Survey Co., Al-Khobar

The above companies are selected from the view point of the industrial policy of the Kingdom. Trading companies, construction companies, retailers and other service companies are widely established in the Eastern province as secondary and tertiary sectors in the wake of the above basic industries. The major companies of all trades in the side of

Eastern Province are shown in The attached data book.

(2) Industrial Features in Eastern Province

Analysis from the data from "Top 1000 Saudi Companies Fifth Edition 1997~98" Indicates that there are many types of companies in this province, however theManufacturing sector, especially extraction of crude oil and oil refineries is dominant in terms of economic size (turnover) which is almost equivalent to 90% of total economy in the region. On the other hand, in terms of job creation, the other sector (construction, commerce and service) undertakes almost 60% of total employment, while the manufacturing sector takes 40%. In this sense, construction and service companies can be regarded as a most reliable source to offer job opportunities to the young Saudi people, particularly because those types of jobs are currently taken extensively by the expatriates. It is indicated that diversification of economy will expand possibility of saudization of human resources which is also one of important goals of KSA. (For detail, refer to Table 2.4.4)

Table 2.4.4 Ratio of Manufacturing Companies to All Companies

	Number of Companies	Number of Employee	Turnover (SR)
Manufacturing	88	96,859	175,136,843,051
All Company	247	245,323	200,544,716,185
Ratio (%)	36%	39%	87%

Source: Top 1000 Saudi Companies (1998)

(3) Industrial Impact on Environment

Al-Jubail, Damman, Dhahran, and Al-Khobar, which make up the core center of Saudi industrialization, are located in within a 200km zone on the eastern coast. Major Manufacturing Companies exist in this area are shown in Table 2.4.5.

All these factories could be potential sources of pollutants, more or less, to the environment, regardless how strictly the pollutants are controlled within the compound of the factories. Based upon project experiences conducted by Chiyoda Dames and Moore, the possibility of pollutants varies depending upon the nature of the factories and may include metals, oil & grease, residual chlorine, alkaline, nitrogen, phosphate, phenol, sulfide, acid, organic substances, etc., In relation with the manufacturing factories, possible sources of pollutants in those cities are assumed and listed in Table 2.4.6.

Table 2.4.5 Major Manufacturing Companies in Saudi EP

No.	Kind of Manufacturing	Number of Companies	Ratio (%)	Number of Employee	Ratio (%)	Turnover (SR)	Ratio (%)
1	Food	6	6.82%	6,998	7.22%	4,160,500,000	2.38%
2	Beverage/Fodder/Cigarette	1	1.14%	61	0.06%	22,831,719	0.01%
3	Textile (Excluding Fabrics)	1	1.14%	66	0.07%	25,000,000	0.01%
4	Furniture	2	2.27%	392	0.40%	75,000,000	0.04%
5	Pulp/Paper	5	5.68%	1,120	1.16%	575,279,000	0.33%
6	Chemicals	16	18.18%	4,879	5.04%	4,903,132,000	2.80%
7	Oil and Coal Products	2	2.27%	59,000	60.91%	157,580,000,000	89.98 %
8	Plastic	9	10.23%	2,878	2.97%	775,500,000	0.44%
9	Ceramic/Soil and Stone Products	11	12.50%	6,208	6.41%	1,886,917,691	1.08%
10	Steel	2	2.27%	396	0.41%	238,646,000	0.14%
11	Metal excluding Steel	1	1.14%	35	0.04%	21,000,000	0.01%
12	Metal Products	17	19.32%	8,336	8.61%	2,636,036,641	1.51%
13	Machine	5	5.68%	3,320	3.43%	794,000,000	0.45%
14	Electrical Machine	7	7.95%	1,960	2.02%	658,000,000	0.38%
15	Other Products (Jewellery, Music Instruments, etc.)	1	1.14%	50	0.05%	25,000,000	0.01%
16	Gas	2	2.27%	1,160	1.20%	760,000,000	0.43%
Total		88	-	96,859	-	175,136,843,051	-

Source: Top 1000 Saudi Comp (1998)

Table 2.4.6 Major Possible Pollutants from Manufacturing Industry in Saudi EP

Group No.	Kind of Manufacturing	Location	Possible Pollutants	
12	Food	Dammam Daharan Alkhobar	Organic Substance Residual Chlorine	Oil & Grease
13	Beverage/ Fodder/ Cigarette	Dammam	Organic Substance Nitrogen	Oil & Grease Phosphorus
14	Textile (Excluding Fabrics)	Dammam	Organic Substance Nitrogen Residual Chlorine	Oil & Grease Phosphorus Metals (Cr)
17	Furniture	Dammam Alkhobar	Organic Substance Organic Solvent	Oil & Grease
18	Pulp/Paper	Dammam Alkhobar	Residual Chlorine	Oil & Grease
20	Chemicals	Dammam Jubail Alkhobar	Metals(Mn, Cr, Pb, Cd, Hg, Fe, Na, As) Organic Substance Oil&Grease Organic solvents (BTEX) Nitrogen (NH_4-N, NO_3-N)	Cyanide (CN) Phenols Phosphorus SS LAS
21	Oil and Coal Products	Daharan Khafji	Phenols Sulphide Organic Solvents (BTEX)	Nitrogen (NH_4-N) Cyanide (CN) Oil &Grease
22	Plastic	Dammam Alkhobar	Organic Solvents (BTEX)	Phosphorus
25	Ceramic/Soil and Stone Products	Dammam Jubail Daharan Alkhobar	Metals (Ca, Pb, Fe, Cd) Organic Solvents (BTEX)	SS Oil &Grease
26	Steel	Daharan Alkhobar	Metals (Fe, Cr, Pb, As, Fe, Hg) Cyanide (CN)	Oil &Grease SS
27	Metal excluding Steel	Jubail	Metals (Pb, As, Cu, Zn, Cd, Co, Fe, Al) Organic solvents	Oil &Grease
28	Metal Products	Dammam Jubail Daharan Alkhobar Sayhat	Metals(Cr, Mn, Zn, Fe, Ni, Pb, Cu, Sn) Organic solvents (BTEX)	Cyanide (CN) Nitrogen (NH_4-N)
29	Machine	Dammam Alkhobar	Organic Solvents	
30	Electrical Machine	Dammam Daharan Alkhobar	Metals(Hg, Pb, Cd, Ni, Hg, Sn, Zn) Organic Solvents (BTEX) Nitrogen (NH_4-N, NO_3-N)	Phosphorus (PO_4-P) Cyanide (CN)
34	Other Products (Jewellery, Music Instruments, etc.)	Dammam	Organic Solvents	
37	Gas	Dammam Alkhobar	Metals	Residual Chlorine

References

IMF, 2000, International Financial Statistics.

IIT, 1997, Top 1000 Saudi Companies, Fifth Edition 1997~98

Ministry of Planning of KSA, Achievement of the Development Plans (1970~98).

World Bank, 2000, World Bank database (World Development Indicators).

World Economic Information Services, 1999, WEIS (World Economic Information Services) ARC Report.

Ministry of Planning of KSA, 1997, Statistical Yearbook 33rd.

2.5 Major Pollution Sources

The major environmental problems in the Gulf are possibly generated by oil and human activities, although effects of them on ecosystem are generally not well known yet. It may be recognized that shoreline of the Arabian Gulf has become the repository zone of waters. Serious major ecological problems have arisen from production loss/degradation of production coastal habitats, due to coastal landfill, dredging and sedimentation.

The distributions of main pollution sources are shown in Figure 2.5.1 and 2.5.2. The outlines of these major pollution sources are described below.

2.5.1 Oil Pollution

Linden et al. (1990) suggested that the most inputs of oil to the marine environment in the Gulf originate from tanker and ship traffic.

Input from tanker and ship traffic originate primarily from discharge of dirty ballast water and other oily water, which during 1986 ranged from 400,000 to 750,000 tones in 1986 in the Gulf (Linden et al. 1990). The entire Arabian Gulf is a major oil tanker and commercial shipping area. Large industrial ports along the Arabian Gulf coast are located at Tanaquib, Saffaniya, Al-Jubayl, Juaymah, Ras Tanura and Damman.

The rest of the marine oil pollution originates principally from refining, industrial and urban sources. Well blowouts during drilling and as a consequence of war activities, can also be a source of oil pollution.

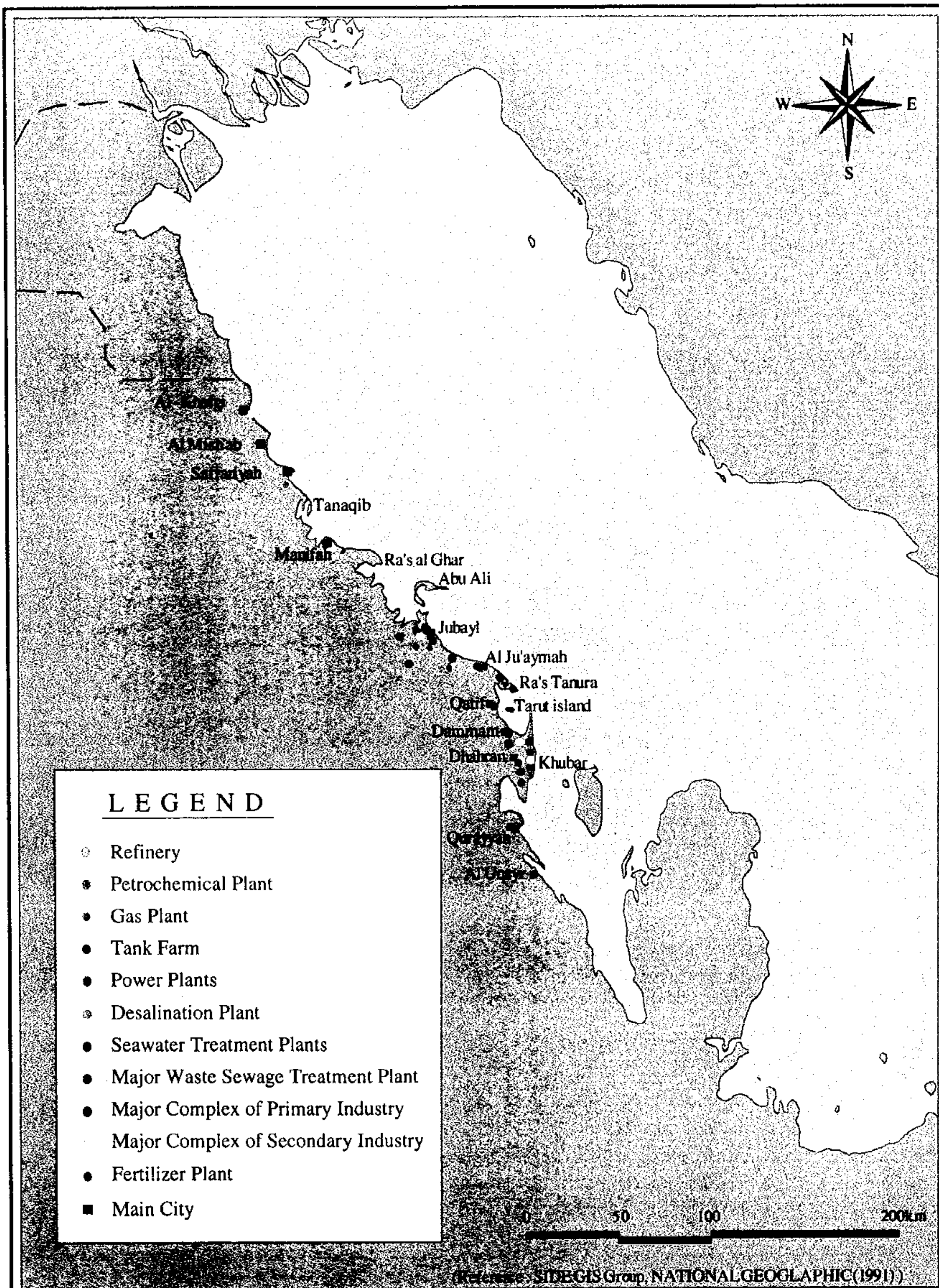

Figure 2.5.1 Distribution of Main Pollution Sources

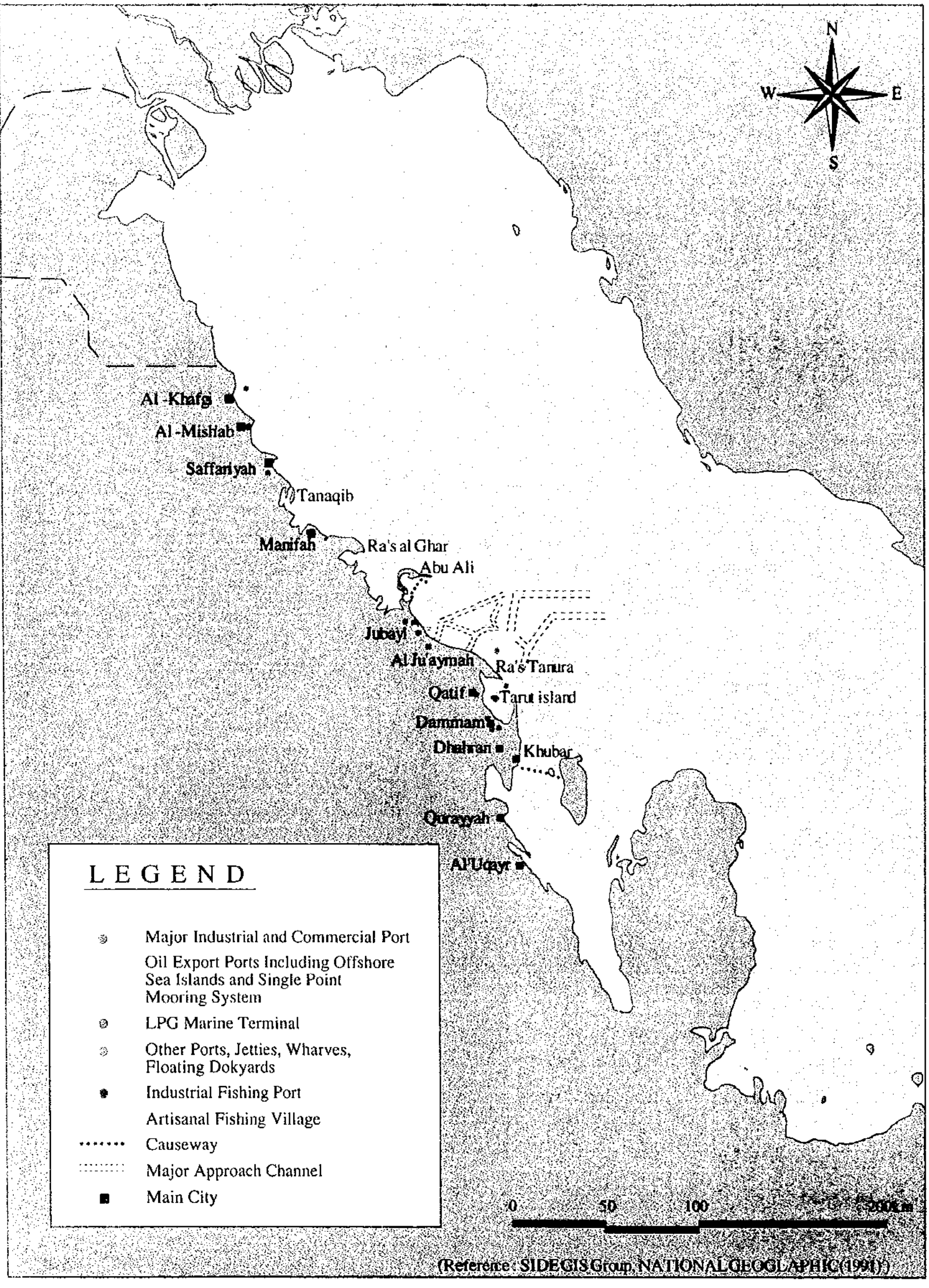

Figure 2.5.2 Distribution of Main Ports and Harbours

Major oil refineries and related facilities such as gas plant, tank farm etc., are located in Zuluf field, Marjan field, Saffaniya field, Tanaquib, Manifah, Abu Ali, Al-Jubayl, Berri, Ras Tanura, Al-Juaymah, Dhahran and Al-Qurayyah.

2.5.2 Wastewater Pollution

Numerous sources contribute to wastewater pollution in the coastal area of the Gulf.
Of domestic and urban sources, untreated sewage and abattoir wastes are discharged at several localities. For instance, in the Saudi Arabian towns of Al-Khobar and Al-Qatif daily inputs of the sewage into the Gulf may be as high as 40,000m^3, equivalent to production by 175,000persons (IUCN 1987). Effects include unsightly solids and grease mats, local eutrophication, increasing biological oxygen demand (BOD) and algal blooms. Sewage treatment plants are helping to alleviate some of these problems. Domestic wastes and pollution are becoming an increasing problem in Oman (Salm et al. 1988).

Industrial facility is also possibly to be significant pollution sources. Industrial facilities are concentrated around Jubayl, Saffaniya, Juaymah, all around Tarut Bay including Ras Tanura, Al-Qatif, Dammam, and Al-Khobar. Industrial developments in these areas include refineries, petrochemical plants, power plants, desalination plants, waste water treatment plants, and other primary and secondary industries.

Among the industrial wastewater from fertilizer plants and refinery and other industrial effluents may contain heavy metals. Elevated concentrations of lead, mercury and copper in bivalves and fish have been reported around some ports and industrial areas. High levels of cadmium, zinc and vanadium have been found in sediments (Linden et al. 1990). However, a recent study revealed that copper and vanadium levels, although comparable to values elsewhere in the Gulf, were an order of magnitude lower than heavily polluted areas in some other part of the world (Coles and McCain1990).

High concentration of heavy metals are reported near some industrial areas of the Red Sea, such as desalination plants (Dicks 1987, UNEP 1987), whose effluents also are normally above ambient temperature (+5°C) and salinity (3ppt: Linden et al. 1990). Chlorine is also used as an ecological effect of effluents may be considerable locally, but probably only minor over larger areas, at least in the Gulf (Linden et al. 1990). Power plants also possibly discharge chlorine and/or high temperature effluent. Major waste sewage treatment plant is in Jubayl, Al-Qatif, Dammam and Al-Khobar and major Power plants are in Saffaniyah, Al-Jubail, Ghazlen, Ras Tanura, Dammam, and Al-Khobar.

2.5.3 Commercial and Residential Development

Along the Arabian Coast, commercial and residential developments are clustered around urban areas. Such developments need transportation systems, water, electricity, sewage and solid waste disposal, and other services, with the cumulative effects causing significant pressure on coastal areas. Moreover, the residents of the coast have an increasing need for recreation facilities, particularly near these urban areas.

On the Arabian Gulf coast, the developments around Jubayl and further south around Tarut Bay/Dammam/Al-Khobar are responsible for a great deal of the coastal land development.

2.5.4 Fishing and Aqua-culture

The fishing industries in the Arabian Gulf utilize the coastal land. However, these uses generally do not create significant disturbances to the environment. Numerous small fishing villages are scattered along the coast and the industrial fishing ports and processing facilities are clustered near the urban areas.
On Tarut Island, there are number of small artisanal fishing villages such as Darin Sanabis and Zur. Near Al-Qatif, there are also two smaller artisanal fishing villages: Saihat and Safwa.

Anchor damage to coral reefs is now highlighted to be a problem on Jurayd island and possibly elsewhere. In addition to fishing, hunting of bird eggs is intensive in some areas. Agriculture appears not to be causing major coastal environmental problems, but further studies are needed.

2.5.5 Coastal Reclamation

Together with dredging, coastal reclamation probably represents one of the most significant impacts on the coastal and marine environment of the Arabian Gulf. Reclamation has been undertaken for residential development, ports, bridges, causeways, cornishe roads and other purposes. Favored areas often have included intertidal flats often with mangroves, shallow embayments and other biologically productive areas, whose true bioeconomic value is seldom recognized by developers. Coastal development and in filling has been far greater along the Gulf coast than in the Red Sea or other par of the Arabian region, where its occurrence is more localized (IUCN 1987). Approximately 40% of the Saudi Arabian Gulf coast has been developed (IUCN 1987), involving extensive infilling and reclamation. Only an estimated 4km^2 of mangroves now remain along these shores (Price et al. 1987a).

Apart from the direct and permanent loss of habitat, landfill usually increases sedimentation. This may directly smother habitats, or may limit photosynthesis of communities such as algal mats, seagrasses and coral reefs (IUCN/UNEP 1985a). Whether this has had measurable effects on the fisheries is not known, but nevertheless has caused concern (IUCN/UNEP 1985a).

2.5.6 Dredging

Dredging provides much of the infill material needed for coastal reclamation hence the two activities often occur simultaneously. The former also takes place to deepen shipping channels and harbors. Like landfill, dredging has taken place most extensively in the Gulf. As a result of projects in Jubayl and Dammam, an estimated 46.5km^2 of coastal habitats have been dredged; and for landfill the residential and industrial areas of modern Jubayl City, more than 200million m^3 of sediments adjacent to the development site (IUCN 1987) were removed. During construction of the Saudi-Bahrain causeway, nearly 60 million m^3 of mud and sand were dredged (Linden et al. 1990).

The ecological effects of dredging are similar to those described above for coastal reclamation, and include both direct habitat loss and various secondary effects. In parts of the Gulf, sedimentation stimulated by dredging has created the soft substrate feeding areas for some species such as waders (IUCN 1987). Some fauna (e.g. birds) may have benefited from new habitats created by sedimentation, for instance in Tarut Bay (IUCN 1987). In general, however, ecological effects of dredging are undoubtedly more adverse than beneficial.

2.5.7 Solid Waste Pollution

Throughout much of the region the coastal zone has become a repository for large quantities of industrial, commercial and residential trash and other solid waste (IUCN1987).

Often this takes the form of plastics, metal containers, wood, tires and even entire scrapped automobiles at some localities (IUCN 1982,1987). In the Gulf, oil sludge constitutes the most important type, in terms of quantity, of solid waste (Linden et al. 1990). Much of the lighter debris has become spread along widespread tracts of shoreline through wind and water movements. During a recent survey, solid waste was encountered at 87% of 53% sites inspected along the Gulf coast (Price et al. 1987b, Price 1990). In recreational areas, solid waste can have ecological as well as aesthetic consequences. In areas containing extensive metal and industrial debris, the potential exists for toxic substances to leach into the marine environment. Wooden pallets and driftwood may form a physical barricade to female turtles crawling up beaches to nest. Further, if such debris becomes impacted by an oil slick, the problem becomes compounded, and also increases dramatically the cost of any future oil clean-up operations. For this reason, several offshore coral islands in the Gulf, where turtles and birds nest in high densities, were cleared of debris shortly after the 1991 war.

2.6 Ecological Condition

2.6.1 Coastal and Marine Habitats

The combination of high temperatures and unusually high salinity makes the Arabian Gulf a stressful environment for marine organisms.
Under such environment, generally, the distribution of organism is not uniform, but mainly confined to particular habitats. So, it is more important to protect the habitats in the Arabian Gulf than common sense.

According to the IUCN/MEPA's report (1988), the principal habitats of the Arabian Gulf were found in the areas of following lands;

1) Coastal wetlands,
2) Intertidal flats
3) Beaches
4) Subtidal sand
5) Subtidal mud
6) Seagrasses
7) Coral reefs
8) Other hard-bottomed biotopes, including rock and artificial structures, particularly oil rigs
9) "Restricted environments" of very high salinity

The details of these habitats are described as bellows.

1) Coastal Wetlands

Because the shoreline of the Gulf is generally low lying, its intertidal zone commonly is distributed hundreds of meters wide. This large intertidal area has grown ecologically important habitats such as mangroves, salt marsh and sabkhah.

- Mangrove

Mangrove is recognized critical and ecologically significant marine habitats. Their fallen leaves and sticks make appreciable contributions to inshore and estuarine productivity. Mangrove ecosystems are also associated with the maintenance of biota, thereby assuming importance as a genetic reservoir. The major nursery function of mangrove roots (e.g., for shrimp and fish) highlights this, and is a feature often exploited by artisanal fishermen and aquaculturists. Mangroves also provide a refuge and breeding area for birds and other marine and terrestrial wildlife (Shepard et al. 1992).

Mangroves occur in the Gulf along the upper intertidal zone in bays, although they tend to be poorly developed and patchily distributed. Only one mangrove species, Avicennia Marina is occurs in the Alabian Gulf, perhaps due to their unusual tolerance for high salinity (about 40 to 50%) and low temperatures (until about 12C°; Hutchings and Saenger 1987).

The northernmost stands of mangroves occur about 27°N for naturally occurring mangroves on the Gulf coast (IUCN 1987) and in Saudi Arabia, their stands are mostly limited in Tarut Bay, Al-Qurayyah, south of Dhahran and between Ras al Ghar and Abu Ali (Taylor 1991). However, in recent years, artificially planted mangroves have been grown on the northern Saudi Arabian Gulf at Al-Khafgi at about 28°30N(Kogo 1986).

- Sabkha

The term sabkha is used to denote hypersaline wetland that is seasonally inundated. They cover some 1,000km^2 in Saudi Arabia, mainly in Tarut Bay, Musharihah and Mssallamiyah (Taylor 1991).

Sabkha forms very flat plains in the coastal area, commonly with periodically filled pools, crusts of sodium chloride and gypsum, with "algal mats" a few centimeters thick, beneath which is black reducing layer with a clear sulfide -odor.

Mats are complex associations of cyanophytes, acteria and diatoms, whose composition is determined by small difference in elevation and frequency of immersion. They remain moist from capillary action in the sediments, from the strongly hygroscopic nature of sabka salts, as well as from physiological adaptations. With increasing isolation from the sea, benthic diversity of the sabkah falls and the persistent microbial biota then forms typical mat. These are highly productive and fix nitrogen.

In many examples in the Gulf, the seaward edge of the sabkha grades into seagrass beds and complex region of shallow patch reefs, mud banks and lagoons (Sheppard et al. 1992).

- Salt marsh

All natural salt marshes and their plant communities are greatly reduced or eliminated throughout the Arabian Gulf coast. However, many new march communities are appearing as a result of sewage outfalls whose fresh water derives from desalination plants. These areas also act as a focus for numerous species of birds, especially migrants.

2) Intertidal Flats

Intertidal habitats such as mudflats are particularly important because they produce a surplus of organic matter and thus provide food for coastal species.

Mud and muddy sand are the predominant marine substrates in the Arabian Gulf and are also exposed as intertidal flats. Along the Arabian Gulf coast these tidal flats are the most important types of intertidal habitat in terms of area (Basson et al. 1977). Even though quantitative data on the productivity of these tidal flats are not yet available for the Gulf, the animal biomass the flats support indicates that they are extremely rich.

Their productivity is thought to be similar to tidal flats in other parts of the world, which are known to be among the most productive of all natural ecosystems. The main sources of primary production in the Gulf are salt-marsh halophytes, mangroves, blue-green algal mats and diatoms (Jones 1985). Since a large proportion of this production is exported (e.g. by fish and birds), these habitats are of great importance of the coastal zone ecosystem as a whole.

3) Beaches

Sandy beaches are of low biological productivity and are dominated by gastropods and ghost crabs (*Ocypode spp.*) They are well distributed in all the Gulf shoreline and are a significant habitat of offshore islands. Some 350km of the Saudi shoreline comprise sandy beaches. They represent important nesting areas for marine turtles and birds (Taylor 1991).

4) Subtidal Sand / Subtidal Mud

In the Gulf, subtidal sandy ecosystems extend down to at least 30m, whereas mud occurs in depths of 6m and more and is also the principal benthic ecosystem at depths greater than 30m (Basson et al. 1977).

Morthensen and Gislen (1941) reported useful information on subtidal sand and muddy benthos in the Gulf. Species richness reported to be high (>600 species) in both subtidal sand and subtidal mud surpassing that of all other ecosystems, even coral reefs (534 species). Polychaetes followed by gastropods were the dominant fauna groups. However, other research has revealed different patterns of species richness and dominance (Coles and McCain 1990). McCain (1984b) reports a significant positive correlation ($p<0.05$) between salinity and the number of major taxonomic groups within subtidal sand. At least four or five biological communities inhabiting subtidal sand and muddy ecosystems of the Gulf have been described (Basson et al 1977). Two of these are found in mud, and have been named after the dominant fauna. One is the "*Murex/cardium*" community (dominated by two molluscs; *M. papyraecum* and *M. Kusterianus*), and the other is the "*Brissopsis/Amphioplus*" community (dominated by two exhinoderms: *B. persica and A. Seminudus*). Jones (1985) suggested that bentic biomass of the Gulf is reduced in mud, and with distance from the open ocean.

Reduced benthic biomass (and diversity) towards the north of the Gulf is also apparent from other studies (Aoki 1974, Enomoto 1971).

5) Seagrasses

Seagrasses are one of the most productive habitats. As sources of food and shelter, seagrass beds are important nurseries for juvenile fish, shrimp, and pearl oysters and are feeding areas for dugong and turtles.

Seagrass in the Arabian Gulf shows a complex distribution pattern, reflecting the heterogeneous nature of the seabed and fluctuating oceanographic conditions. In Arabian Gulf waters, well-developed stands occur within a number of shallow (<10m) coastal embayments (Basson et al. 1977, IUCN/UNEP 1985a, IUCN 1987). However, the total area within these waters may constitute only a small proportion (1%) of the subtidal zone (IUCN 1987, Price et al. 1987a). There is a significant correlation between total seagrass cover and salinity, even though salinity and latitude together show strong negative correlation.

In Saudi Arabia, seagrasses are abundant in several shallow water embyments (less than 10m) along the coast. Important areas are between Saffaniya and Manifa, west and south of Abu Ali, east of Al-Khobar, Taru Bay, Dawhat Zalum and the Gulf of Salwa (IUCN/MEPA, 1988).

Eleven seagrass species have been recorded from the Arabian region. Among the species, only four species have been recorded along the Arabian Gulf coast. They are "*Halodule uninervis*", "*Syringodium isoetifolium*", "*Halophila ovalis*" and " *Halophila stipulacea*" (Basson et al., 1977; IUCN/MEPA, 1988).

6) Coral Reefs

Coral reefs provide food and shelter for a multitude of plants and animals, and a refuge for several large commercial fish species.

The Gulf is located at the northerly limit of coral reef distribution around the world. Because of seawater fluctuations of temperature and salinity, the Gulf has to have a characteristic of highly stressful environment for corals. The reefs, therefore, are not very diverse compared to truly tropical areas.

The 1987 IUCN reported that the best reefs in the Gulf are along the Saudi coast. The most important area is probably around the islands of Karan, Kurayn, Jan, Jurayd, Harqus and Arabiyah. Coral diversity is higher here (over 50 species), but this is still low by general Indian Ocean standards. South of Ras Tanura, reef development and diversity decline because of increasing salinity and sedimentation in the Gulf of Salwah (Taylor 1991).

7) Other Hard-Bottomed Biotopes

The major species of this sector are recognized as dense brown algae dominated by kelp *Ecklonia radiata, Sargassum spp., Padina sp.* and *Colpomenia spp.*, amongst which numerous molluscs, particularly gastropods and several bivalves. Sponge species also occur. Subtidal rocky habitats occur along much of the west gulf coast, especially in inshore waters, but are very patchy and of rather limited occurrence.

Important seaweed beds occur in Kuwait bay. In Saudi, the greatest concentrations are around Al-Mishab, Abu Ali, Juaymah and Tarut, Al-Khobar and the Gulf of Bahrain. The majority of the Iranian coastline is rocky in character.

Seaweed beds have been shown to support over 650 species of animal and plant, mud bottom habitats to support over 600 species, rock bottom habitats to support some 200 species. Subtidal sand and mud habitats represent important fishing grounds (Taylor 1991). Subtidal rock habitats, rich in seaweed beds, are economically important for shrimps, pearl oysters and abalone fisheries (e.g., Kuwait Bay and Tarut Bay, Saudi Arabia).

2.6.2 Key Species

The key species (and/or important species) in the Arabian Gulf are described as follows;

1) Birds

Arabian Gulf, particularly the intertidal flats, is one of the most important habitats in the world for both resident and migratory birds. An estimated 1-2 million birds overwinter or stop on migration (Taylor 1991) and at least 70 species of coastal and marine birds have been observed during winter counts in the Gulf region.
These can be broken down into the following groups:

Waders: Over 30 species. Following species are dominant in the Arabian Gulf: Grey Plover, Kentish Plover, Lesser Sandplover, Ringed Plover, Eurasian Curlew, Redshank, Little

Stint, Dunlin, Curlew Sandpiper and Broad-billed Sandpiper.
Almost all of the Saudi coastline are sandy with no large populations of waders, except for Tarut Bay and the adjacent coast where may grow as many as 30,000 wintering waders.

Gulls and terns: Around 13 species, with by far the commonest species being the Herring Gull, the Black-headed Gull and the Slender-billed Gull. There are also eight species of tern: the Caspian Tern, Greater Crested Tern, Lesser Crested Tern, Common Tern, White-cheeked Tern, Bridled Tern, Saunders' Tern and the Little Tern. They breed on the islands and marshes of the region. A survey of breeding terns on five Saudi Arabian Gulf coral islands in 1986 revealed a total of 9,110 Bridled Terns, 12,380 White-cheeked Terns and 26,340 Lesser Crested Terns.

Grebes: including the Black-necked Grebe. Pelicans: notably the Dalmatian Pelican. Cormorants: notably the Great Cormorant, the *Socotra Cormorant* and possibly the *Pygmy Cormorant.*

Herons and Egrets: the commonest species are the Grey Heron and the Western Reef Egret. Other species include the White Spoonbill and the Greater Flamingo, which has quite sizeable populations throughout the region.

The *Socotra Cormorant* is a threatened species and is of particular concern as its main breeding area is the Gulf, although it does extend marginally to the Gulf of Aden.
Significant areas of this species in Saudi Arabia are Al Uqayr Bay and Zakhnuniyah Island.

2) Marine Turtles

Two marine turtles species, Green Turtle (*Chelonia mydas*) and Hawksbill Turtle (*Eretmochelys imbricata*) are common, and are widely distributed (Basson et al. 1977, Miller 1989) in the Arabian Gulf. However, their nesting area is restricted geographically and seasonally. Most nesting areas were recorded on the offshore islands although a few were found on the mainland. In the Saudi Arabian Gulf, most of the population breeds on offshore islands include Karan, Kurayn, Jana, Harqus, and Jurayd. Particularly Karan and Jana are the primary nesting site for these species (IUCN/MEPA 1987).

In addition to these two species, following three additional species occur in Gulf waters, but have not been recorded to nest: Leatherback Turtle (*Dermochelys coriacea*), Loggerhead Turtle (*Caretta caretta*), and Olive Ridley Turtle (*Lepidochelys olivacea*).

All five are listed as globally threatened species in the 1990 IUCN Red List of "Threatened Animals", all with category "Endangered", except the logger head which is listed as "Vulnerable".

3) Marine Mammals

The marine mammals found in the Arabian Gulf include several species of dolphins, whales (Pilot, humpback, killer, fin) and dugong (IUCN/MEPA 1987).

- Dolphins and Whales

There have been no systematic surveys of whales or dolphins in any of the coastal waters of the Arabian region. But at least a dozen species of dolphin, and the finless porpoise, have been recorded in the Arabian Gulf.

Of the baleen dolphins, Humpbacked, bottle-nosed and common dolphin is dominant.
The Humpbacked Dolphin (*Sousa chinensis*, in part includes *Sousa plumbea*) is found close inshore around sea coasts, preferring shallow waters less than 20 m deep and frequenting mangrove channels, bays and shallow banks in river deltas. Its distribution extends from the southern tip of Africa to the Red Sea, around the coast of the Arabian Peninsula into the Gulf, and eastwards around the Indian subcontinent to the shores of Myanmar, Thailand, Indonesia and Malaysia. It is classed by IUCN as "Not threatened" i.e. likely to qualify as a threatened species if current factors continue operating.

The Bottlenose Dolphin (*Tursiops truncatus*) is found throughout the temperate and tropical seas of the world, including the Gulf. Coastal populations occur in waters less than 30 m deep; others live further out to sea. The species is fairly common, and is currently listed by IUCN as "Not threatened" i.e. likely to qualify as a threatened species if current factors continue operating.

The Common Dolphin (*Delphinus delphis*) is found in warm temperate and tropical waters throughout the world, including the Gulf. It occurs mainly in relatively deep offshore waters, but some live in shallow coastal areas. The species is currently listed as threatened species by IUCN.

Of the baleen whales, Bryde's Humpback, Minke, Fin and Blue whales have been recorded, and as the toothed whales, Sperm whale, Killer whale and False Killer Whale have been recorded (IUCN/MEPA 1987).

Bryde's whale is the species which includes fish in its diet to the greatest degree, and perhaps is the most likely to be found in the Red Sea and Gulf (IUCN/UNEP 1985b). The Finless Porpoise (*Neophocaena phocaenoides*) has only been rarely recorded from the Arabian Gulf and is found in shallow, warm waters. It is listed by IUCN as "Not threatened" i.e. likely to qualify as a threatened species if current factors continue operating.

- Dugong

The dugong categorized as 'Vulnerable' in the 1990 IUCN Red List of Threatened Animals. Most populations are under threat or known to be declining.

The species was believed exceedingly rare in the Gulf. However, a recent studies carried out in parts of the Gulf (Preen 1989) revealed considerable numbers of dugong in this areas. Preen (1989) estimated overall dugong population between Ras Tanura and Abu Dhabi to be at least 3,760 and possible as high as 7,500 individuals. They are at their most abundant in the Gulf of Salwah between Bahrain and Qatar, and occur also in significant numbers amongst the shoals and islands west of Abu Dhabi.

According to the IUCN/MEPA report (1987), the most important areas for dugongs in the Arabian Gulf are:

a. Between Abu Al Abyad Island, Jabal Dhannah and Bu Tinah shoal in the UAE.
b. Khawr duwayhin including Ghaghah Island in Saudi Arabia, between Quatar and the UAE.
c. Between Bahrain and Qatar, south of Fasht Adm and north of the Hawar Islands.
d. Between Saudi Arabia and Bahrain, south of the Causeway and north of Uqair.

4) Sea Snakes

At least nine species of sea snake (*Hydrophiidae*) occur in Gulf waters (see list below). A further two species are present in the Arabian Sea (northern Indian Ocean) and might also occur in the Gulf.

Although elsewhere in the range certain species have locally been observed in great abundance, very little is known about the population status of sea snakes in general, and virtually nothing about their status in the Gulf. None of the following species known to occur in the Gulf is currently identified as of special conservation concern:

Enhydrina schistosa, Hydrophis cyanocinctus, H. lapemoides, H. ornatus, H. spiralis, Lapemis curtus, L. viperina (= Praescutata viperina), Microcephalophis gracilis (= Hydrophis gracilis), Pelamis platurus

2.6.3 Ecologically Sensitive Area

The Saudi Arabian Government in association with IUCN-The World Conservation Union, has drawn up an extensive list of important marine and coastal nature conservation areas in the country (IUCN/MEPA 1987).

The following is a list of the environmentally sensitive areas (ESAs) and their habitats/ resources.

1) Saffaniya/Manifah Bay Complex
   Coral reefs, Important mangroves and seagrass beds, nesting site for green turtles, pearling banks, and fishery resources
2) Harqus Island
   Key sites for nesting green turtles and birds.
3) Arabiyah Island
   Well-developed coral reefs
4) Karan Island
   Primary nesting site for marine turtle (Green Turtle and Hawksbill Turtle), nesting site for birds.
5) Kuayn Island
   Key sites for nesting green turtles and birds.
6) Jana Island
   Key sites for nesting green turtles and birds.
7) Jurayd Island

Key sites for nesting green turtles and birds.

8) Abu'Ali/Dawhat Dafi/ Musallamiyah Complex

Seagrass bed, coral reefs, pearling bank, and fishery resources.

9) Tarut Bay Complex

Coral reefs, critical mangrove areas, well developed seagrass beds, habitat of Dugong or sea cows and sea turtles, pearling bank, fishery resources

10) Al'Uqayr Bay

Primary breeding area of Socotra Cormorant (threatened bird species).

11) South Gulf of Salwah

Seagrass bed, Habitat of Dugong or sea cows and sea turtles, fishery resources.

The distribution of these ecologically sensitive areas are shown in Figure 2.6.1

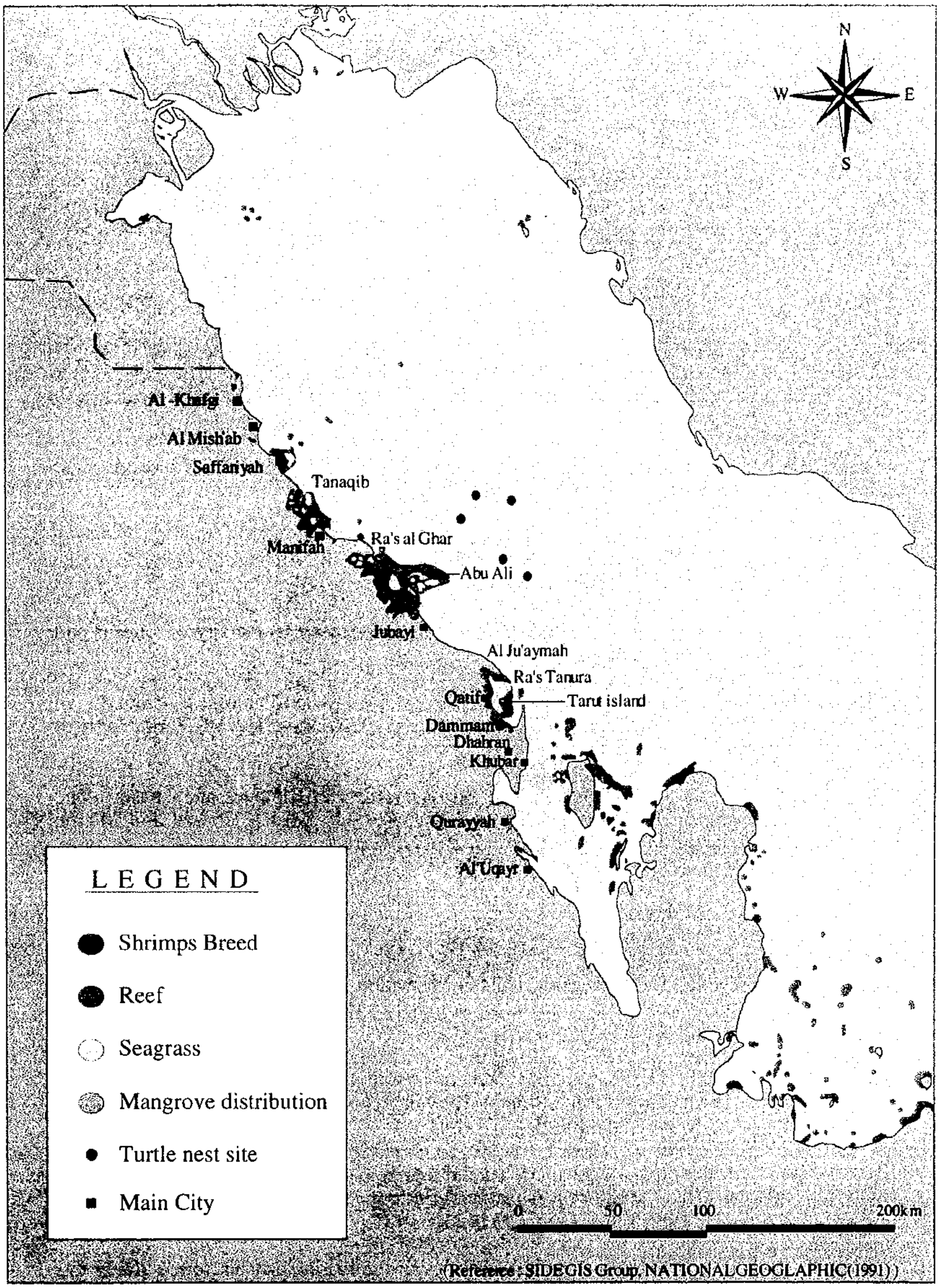

Figure 2.6.1 Distribution of Ecologically Sensitive Areas

References

Aoki, S., 1974, Dredging of bottom deposits and benthos, including mineralogy in fine sediments of the Arabian Gulf, In: Kuronuma, K. (ed.), Arabian Gulf fishery-oceanography survey, Transaction of the Tokyo University of Fisheries, No.1, 52-56.

Basson, P. W., Burchard, J. E., Hardy, J. T. and Price, A. R. G., 1977, Biotopes of the Western Arabian Gulf, Aramco, Dhahran.

Coles, S. L. and McCain, J. C., 1990, Environmental factors affecting benthic communities of the western Arabian Gulf. Marine Environmental Research, 29, 289-315.

Dicks, B., 1987, Pollution. In: Edwards , A. and Head, S. M. (eds.) Key Environments, The Red Sea, Pergamon Press, Oxford, 383-404.

Enomoto, Y., 1971, Oceanographic survey and biological study of shrimps in the waters adjacent to the eastern coast of the state of Kwait, Bulletin of Tokai Regional Fisheries Research Laboratory, 65, 1-74.

Hutchings, P. and Saenger, P., 1987, Ecology of Mangroves, University of Queensland Press, Queensland.

IUCN, 1982, Management requirements for natural habitats and biological resources on the Arabian Gulf coast of Saudi Arabia, IUCN/University of York report to MEPA.

IUCN, 1987, Arabian Gulf, Saudi Arabia, An Assessment of Biotopes and Coastal Zone Management Requirements for the Arabian Gulf, MEPA Coastal and Marine Management Series, Report No. 5, IUCN, Gland.

IUCN, 1990, IUCN Red List of Threatened Animals, IUCN, Gland, Switzerland and Cambridge, UK.

IUCN/UNEP, 1985a, The management and conservation of renewable marine resources in the Indian Ocean Region in the Kuwait Action Plan region, UNEP Regional Sea Reports and Studies, No. 63.

IUCN/UNEP, 1985b, The management and conservation of renewable marine resources in the Indian Ocean Region in the Kuwait Action Plan region. UNEP Regional Seas and Reports and Studies, No. 64.

IUCN/MEPA, 1988, An analysis of coastal and marine habitats of the Saudi Arabian Saudi Arabian Red Sea, Report to Meteorology and Environmental Protection Administration, Saudi Arabia, February 1987.

Jones, D. A., 1985, The biological characteristics of the marine habitats found within the ROPME Sea Area. Proceedings of ROPME Symposium on Regional Marine Pollution Monitoring and Research Programs, (ROPME/GC-4/2), 71-89.

Linden et el., 1990, State of the marine environment in the ROPME Sea Area. UNEP

Regional Sea Reports and Studies, No. 112, Rev.1, UNEP, Nairobi.

McCain, J. C., 1984, Marine ecology of Saudi Arabia, The nearshore, soft bottom benthic communities of the northern area, Arabian Gulf, Saudi Arabia, Fauna of Saudi Arabia, 6, 79-97.

Miller, J., 1989, Marine turtles, Vol. 1, An assessment of the conservation status of marine turtles in Saudi Arabia, MEPA, Coastal and Marine Management Series Report, No.9, MEPA, Jaddah.

Mortensen, Th. and Gislen, T., 1941, Echinoderms from the Iranian Gulf, Asteroidea, Ophiuroudea and Echinoidea, In: Jassen, K. and Sparck, R. (eds.) Danish Scientific Investigations in Iran, Part II. Einar Munksgaard, Copenhagen.

Preen, A., 1989, Dugongs, Vol. 1, The status and conservation of Dugongs in the Arabian Region, MEPA Coastal and Marine Management Series, report No. 10, MEPA, Jeddah.

Price, A. R. G., 1990, Rapid Assessment of coastal zone management requirements, case study in the Arabian Gulf. Ocean and Shoreline management, 13, 1-19.

Price, A. R. G., Chiffings, T. W., Atkinson, M. J. and Wrathall, T. J., 1987a, Appraisal of Resources in tha Saudi Arabian Gulf, In: Magoon, O. T., Converse, H. Miner, D. Tobin, L. T. Clark, D. and Domurat, G. (eds.) 5th Symposium on Coastal and Ocean Management, Vol. 1, American Society of Coastal Engineers, New York, 1031-1045.

Price, A. R. G., Wrathall, T. J. and Bernard, S. M., 1987b, Occurrence of tar and other pollution along the Saudi Arabian Shores of the Gulf, Marine Pollution Bulletin, 18, 650-651.

Reynolds, M., 1993, Physical Oceanography of the Gulf, Strait of Hormuz and Gulf of Oman – Results from the Mt Mitchell Expedition, Marine Pollution Bulletin, 27, 35-59.

Salm, R., Dobbin, J. A. and Papastavrou, V. A., 1988, Oman Coastal Zone Management Plan, Quiryat to Ras Al Hadd, IUCN, Gland, 56.

Sheppard, C., Price A. and Roberts, A., 1992, Marine Ecology of the Arabian Region, Patterns and Processes in Extreme Tropical Environments, Academic Press Limited, UK.

Taylor, J, 1991, Gulf war impact on marine environment and species, http: // scilib. ucsd. edu. / sio. / guide / zgulfwar. html.

UNEP, 1987, State of the marine environment in the Red Sea region (Draft), UNEP Regional Sea Reports and Studies.

Chapter 3

Status of Environmental Management

Chapter 3 Status of Environmental Management

3.1 General Description

The Islamic principles teach man that the Universe was created in balance by God, and that man as steward of God should manage all the created beings fairly and equally to enhance the universal common good of them not only for the current generation but also next generations. Based on the Islamic taught, the people of the Kingdom of Saudi Arabia had lived on the benefits of the nature, paying due attentions to the natural environment.

During these decades, the Kingdom has been experiencing the most rapid economical development in line with its industrialization originated by the enormous amount of revenues from the oil industries. Through the consequent urbanization, the social structure has also undergone a considerable change from the traditional nomadic life with a subsistence economy to modern city life with a market economy accompanied by an explosive increase of population mainly on the coastal area of the Arabian Gulf and the Red Sea. All these changes are incurring new types of stresses on the environment of the Kingdom. The Saudi government has established a number of administrative agencies and legal orders in order to cope with the environmental protection in the modern Kingdom, along with the resolutions of many international organizations and councils. However, there are many impending issues yet to solve.

3.2. Governmental Activity

3.2.1 National Policy

As seen above, the fast economic development, industrialization and urbanization of Saudi Arabia are socially characterized phenomena

Geographically the Kingdom is flanked by the Red Sea on the west and the Arabian Gulf on the east. Both are featured as semi-closed seas, oil producing sites and busy passage of tankers and ships which carry out and carry in a tremendous amount of oil and general cargoes to and from all over the world. On top of that, there were a number of conflicts and wars* between the surrounding countries which imposed serious damages to the natural environment. The Saudi Government well realizes the vulnerability of the environmental conditions of the Kingdom and emphasizes the importance of protection of its land, seas and air from any environmental hazards.

In 1981, the Government created Meteorology and Environment Protection Administration (MEPA) as a directly responsible entity for the environment under the Ministry of Defense and Aviation by Royal Decree No. 7/M/8903 to control pollution, protect environment and set up standards related to pollution control and environment protection and also in 1986, similarly created National Commission for Wild Life Conservation and Development (NCWCD) by Royal Decree No. M/22 specifically to protect wildlife including national fauna and flora in danger of extinction. Along with the two entities, the government established in 1981 " Environment Protection Coordination Committee" to coordinate among the ministries and governmental departments, and in 1990 "Ministerial Committee for Environment" as the highest level directorate to deal with environment affairs on the national level in the Kingdom. Lately the system has been partially amended for strengthening of the system. (see Figure 3.2.1 Environment Protection System of Saudi Arabia).

*Ex.: Iran-Iraq War in 1980, Gulf War in 1991

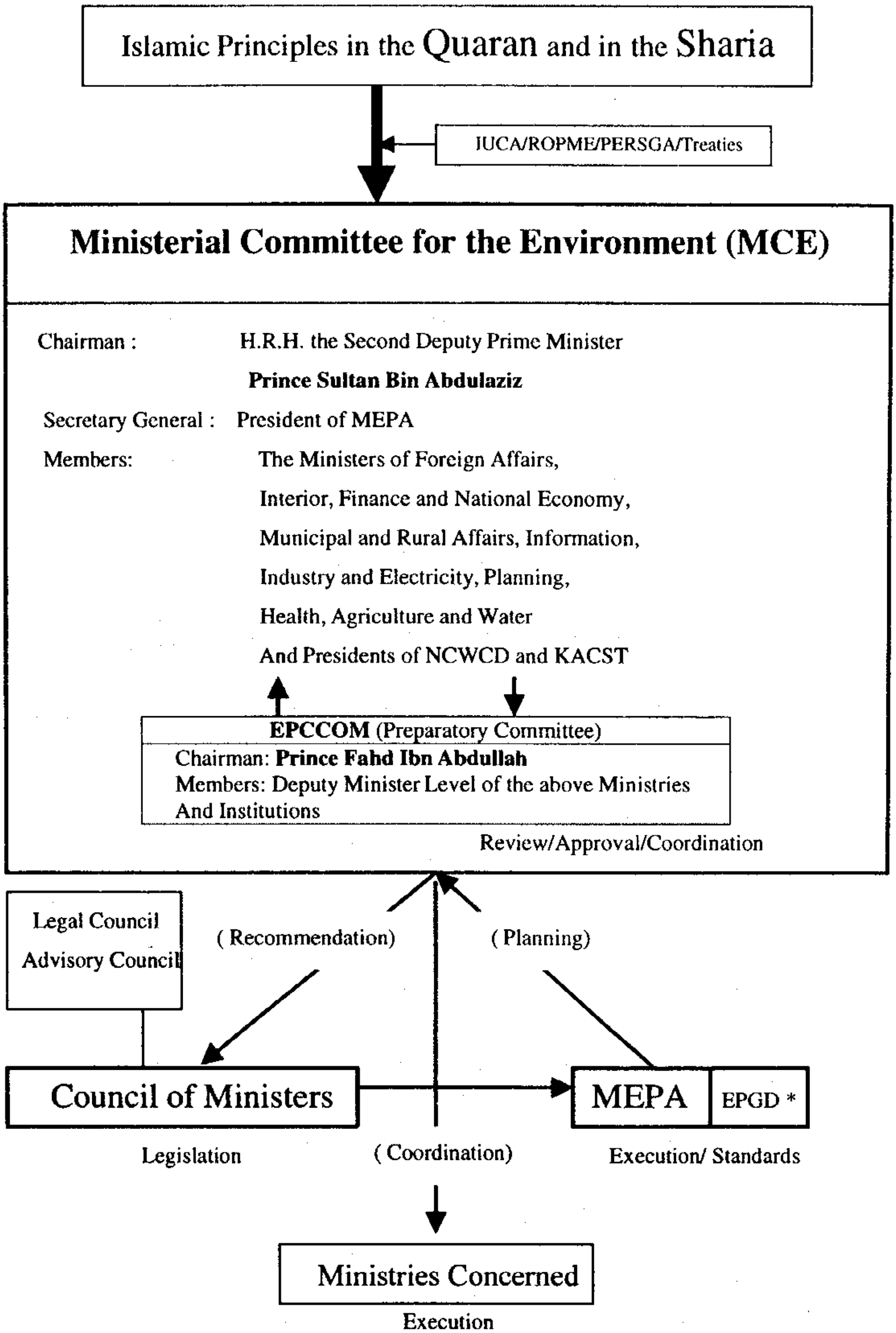

Figure 3.2.1 The Environment Protection System of Saudi Arabia

3.2.2 Environmental Laws and Standards

Although the draft of National Legislation for protection of the environment is yet to be formalized, the Islamic principles have been philosophically effective to date over the mind of Saudi Arabian people. According to the Holy Koran, " God created all species in balance and thus man is obliged to observe moderation and avoid anything that may affect the environmental balance".

The Islamic rules are interpreted by MEPA and The World Conservation Union (IUCN) as guidelines of Moslems for the environment protection. The book is titled "Environment Protection in Islam" 2nd revised edition in 1994.

Besides the Islamic principles, the Saudi Government issued a number of administrative orders in the forms of royal decrees, royal orders, ministerial resolutions, and MEPA standards as follows:

- Royal Decree No.M/22(3/5/1398H:1979G) which defines the natural range-lands.
- Royal Decree No. M/26(25/5/1398H:1979G) which regulates birds and wildlife hunting system.
- MEPA No. 1401-01 Environmental Standards which were put into effect as of the 1 /11/ 1402(1982)
- Ministerial Resolution No.271(23/11/1404H:1984G) which regulates for industrial activities (cement and gypsum).
- Royal Order 1182/8(5/7/1405H:1985G) which regulates for forest protection.
- Ministerial Resolution No. 157(20/11/1411H:1991G) which regulates against sea pollution.
- Royal Decree No.A/90(27/8/1412H:1992G) which delegates specific roles to the governmental departments.

In addition to the above, the Kingdom has extensively participated in regional and international organizations , and/or signed several important agreements with them for cooperation in environment protection and preservation such as:

- United Nations Environment Program (UNEP)
- United Nations Development Program (UNDP)
- The World Conservation Union (IUCN)
- Inter-governmental Oceanographic Commission (IOC)
- The Arab League Decisions 1407H(1986) which adopted "the Arab Declaration on Environment and Development"

- The Advisory Committee on Protection of the Sea (ACOPS)
- Decision of the Heads of State of the Gulf Cooperation Council 1407H(1983)
- Regional Organization for the Protection of the Marine Environment (ROPME) signed by eight states on the Arabian Gulf and Oman.
- Saudi Sudanese Joint Red Sea Commission
- Regional Organizations of the Red Sea and Gulf of Aden (PERSUGA)
- Center for Environment and Development for Arab Region and Europe (CDARE)

3.2.3 Environment Related Authorities

The governmental authorities directly involved in environmental protection management are MEPA and NCWCD namely;

MEPA: Meteorology and Environmental Protection Administration.
NCWCD: National Commission for Wildlife Conservation and Development.

In addition, the central government clearly described the responsibility of each ministry and other government departments in environmental protection by Royal Decree No.A/90 dated 27/8/1412H (1992) as follows:

- Ministry of Agriculture & Water:
  It implements the national plans concerning use of pasturage, forest and agricultural land, and development of desalination plants on the coast of both the seas ; Red Sea and Arabian Gulf, and also it is responsible for organizing, developing and observing the land, water, pasturage and forests besides issuing any permits related to agricultural water resources and fishing.

- Ministry of Finance and National Economy:
  It provides the necessary funds for the environmental projects that the governmental departments propose.

- Ministry of Petroleum and Mineral Resources:
  It implements several environmental activities through Saudi Aramco Co. (a government company working under this ministry) and the Arabian Oil Co. which has been recently (Mar.2000) transferred to the control of Aramco from this ministry. All the environmental activities of this ministry are to be coordinated with MEPA.

- Ministry of Health:

Its responsibilities are represented in provision of health care and control of environment and professional health conditions

- Ministry of Industry and Electricity:
  It issues the industrial projects licenses besides its responsibility for electricity.

- Ministry of Interior:
  It takes over the duties of evaluating the chemical, radioactive, military and natural hazards.

- Ministry of Transportation:
  It assumes the responsibility of transporting the dangerous wastes, besides preventing oil spillage from ships and any sea pollutants.

- Ministry of Planning
  It defines the objectives of the economic, social and environmental development through the Kingdom quinuennial development plans.

- Ministry of Municipal and Rural Affairs:
  It controls the works of water and sanitary systems, besides disposal of solid wastes (industrial, medical, construction). It has a department for environment affairs taking over the public health matters.

- Ministry of Information
  It promotes awareness of the nationals for environment protection.

- Ministry of Trade
  Its responsibility includes the establishment of standards for merchandise to protect the environment.

- Royal Commission for Jubail and Yanbu:
  According to an understanding memorandum with MEPA, the Royal Commission assumes all responsibilities related to environmental protection in the industrial cities of Al-Jubail and Yanbu. The Royal Commission observes the environmental issues, air pollution and wastes control according to a strict system similar to MEPA systems.

- The Higher Committee for Riyadh City Development
  Its responsibility includes planning and implementing the development

programs of Riyadh city on continual basis and in coordination with MEPA.

- King Abudulaziz City for Science and Technology
  It deals with improvement and better usage of national resources.

3.2.4 MEPA's Activity

(1) History

In line with fast economic development in the Kingdom, the problem of environmental pollution was becoming an area of concern. Specifically oil spills were continuously threatening the Saudi territorial water of the Gulf. To cope with such situations, in 1981 the Government reorganized the ever existing "General Directorate of Meteorology" to "Meteorology and Environmental Protection Administration" under the Ministry of Defense and Aviation by Royal Decree No. 8903 dated 21/4/1401.

(2) Organization

As historically seen above, the environment protection administration department was newly added to the meteorology administration department under the Ministry of Defense and Aviation. Although MEPA belongs to the military organization, the personnel and function are regarded totally as civilians. The MEPA Head Office organization chart is shown in Figure 3.2.2.

(3) Role and Responsibility

MEPA is assigned to undertake the following activities:

- Conduct environmental surveys and monitoring to define problems and recommend environmental standards and measures.
- Recommend practical measures necessary to deal with emergency situations affecting the environment.
- Recommend protection regulations and measures dealing with environmental problems and do environmental assessment.
- Assess existing environmental pollution levels and future variations (such information to be documented for easy retrieval).
- Keep abreast with development in the field of environmental protection on the regional and international levels.
- Establish environmental standards and specifications for pollution control and environmental protection, in a definite and stable form to be considered by the appropriate authorities when issuing permits for industrial and agricultural projects which may have an environmental impact.

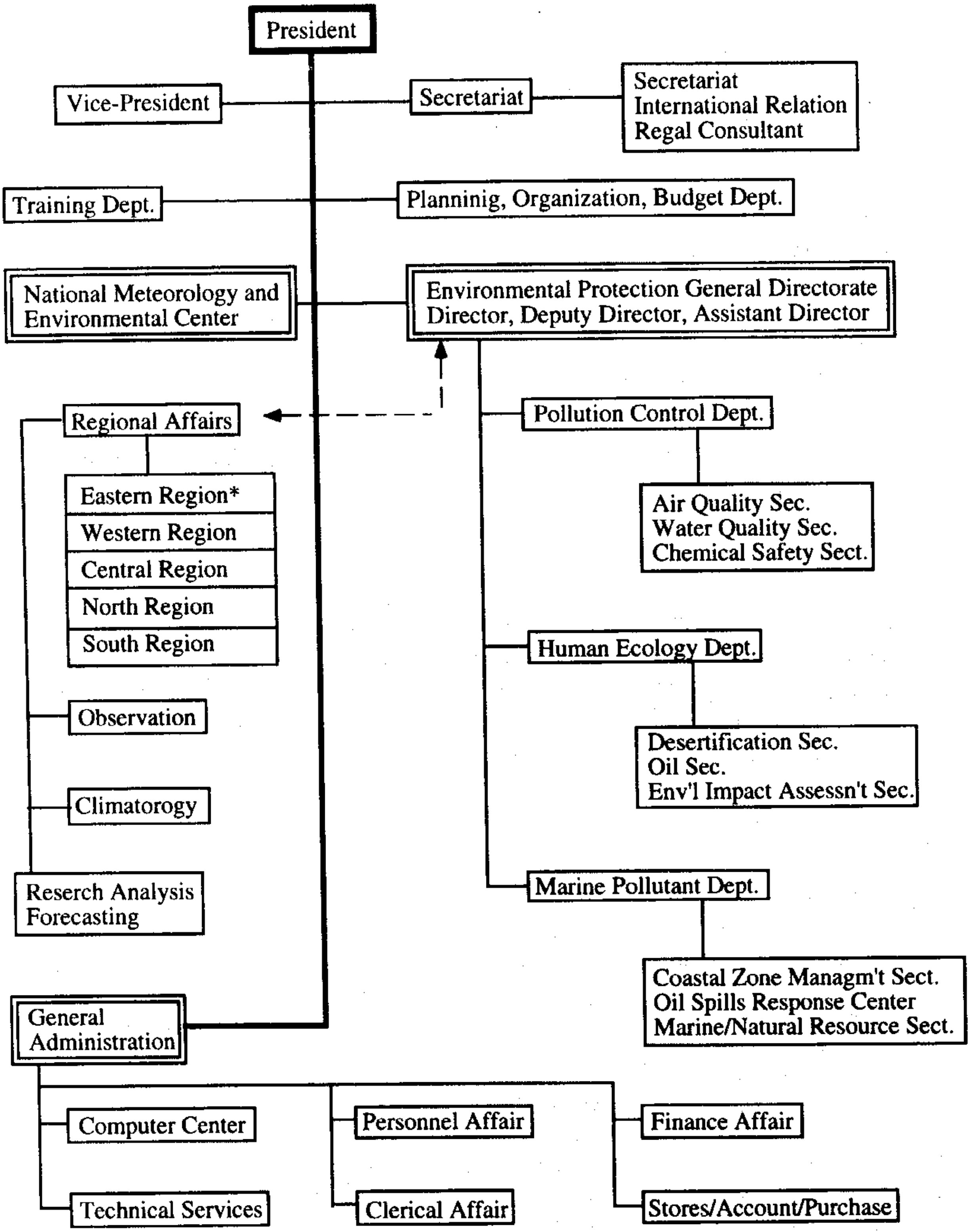

Figure 3.2.2 MEPA Head Office Organization

3.2.5 Practical Activities of MEPA's Eastern Province

(1) Organization

From the MEPA head office organization, MEPA Eastern Province Office (Eastern Office) is situated under National Meteorology and Environmental Center, not under Environmental Protection General Directorate. As seen in Figure 3.2.3 MEPA Eastern Province Organization, the number of personnel at Meteorology Division of the Eastern Office is much more than at Environmental Protection Division.

(2) Role and Responsibility

Since there is no written document available about designated responsibilities of the Eastern Office, only assumption can be made from the organization chart and interviews with the staff members as follows:

- Meteorological observation
- Meteorological record keeping and analysis
- Deal with marine pollution
- Deal with hazard waste management
- Deal with air pollution
- Deal with oil spill problems
- Laboratory
- Maintenance of facility and equipment
- Any other items designated by MEPA head office.

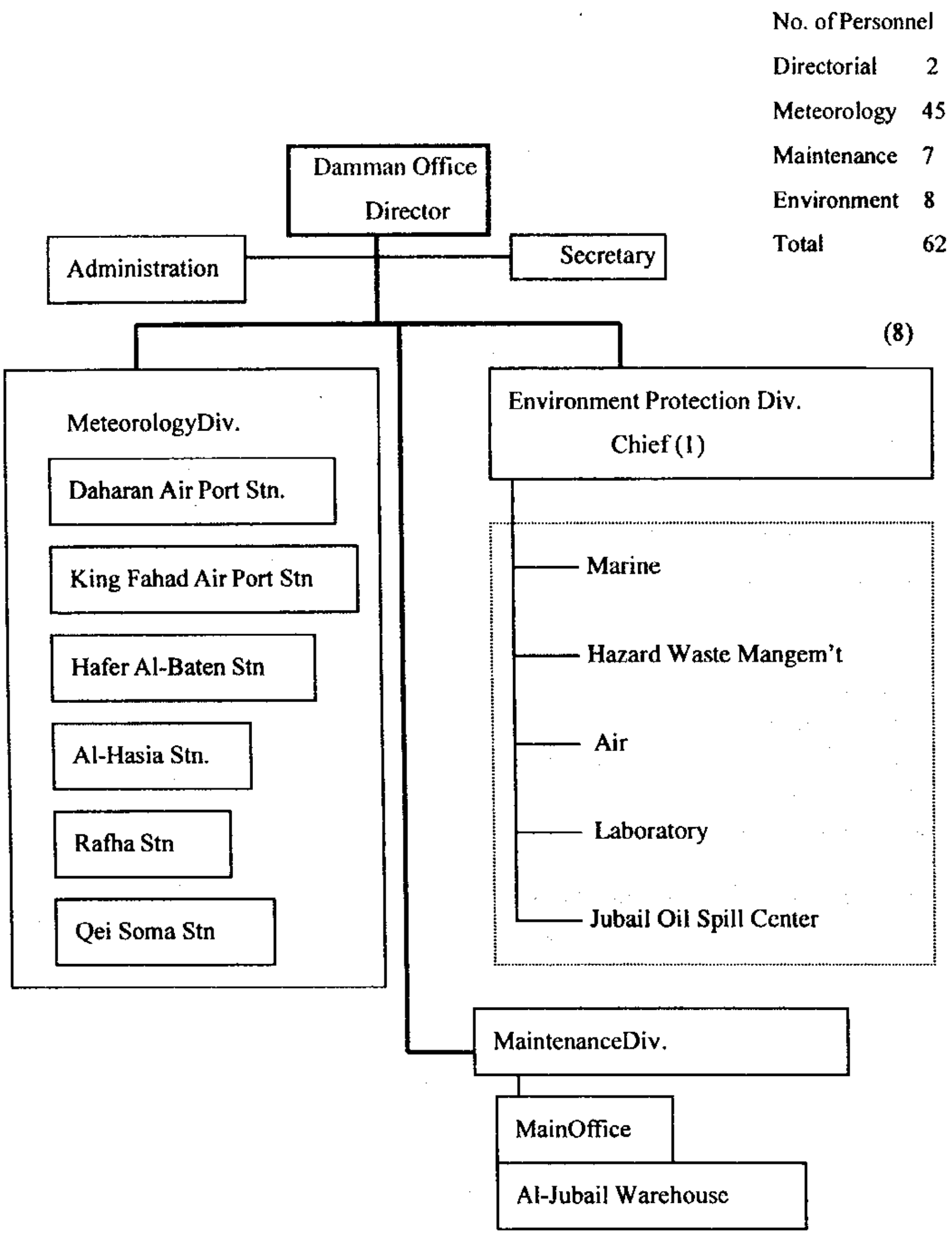

Figure 3.2.3 MEPA Eastern Province Organization

(3) Laboratory condition

For the laboratory space, approximately 450m^2 in total is allocated in the Eastern Office building. The space is divided into several sections including manager's office, stock room and laboratories. The laboratory has tap water, sinks, experimental stands. However MEPA EP had few equipment and chemicals so that it was difficult to carry out the Project with these equipment. JICA provided the Eastern Office with necessary equipment and chemicals. In order to implement the monitoring and analytical work in the laboratory,
MEPA needed to assign several specialists as counterparts to carry out the analytical work of the Project and direct recipients of the technology transfer.

(4) Budget Condition

It is assumed that all expenditures of the Eastern Office are controlled by the head office. For example, the expenses accrued on routine works such as salary and maintenance cost are already determined by its head office and expenses accrued on ad-hoc basis are basically reimbursed by the head office if they are permissible within the budget of the head office. Since there is no separate budget for laboratory and laboratory management and maintenance is directly under the control of contract department of MEPA (The Planning, Organization Budget Department shown in the Figure 3.2.3). So MEPA E. P. do not have authority to maintain or to purchase any kind of chemical/spare parts or even small equipment unless it is approved by the contract department.

Chapter 4

Status of Actual Environment

Chapter 4 Status of Actual Environment

4.1 Outline of the Studies Having been Conducted

It is one of the most important objectives of this study to evaluate the present water pollution condition in coastal area of the Arabian Gulf. Following investigations categorized in this matter have been conducted.

1) Satellite Image Analysis
2) Preparative Field Inspection
3) Monitoring Investigation

Satellite Image Analysis was conducted to reveal overall water pollution condition of the Arabian Gulf area by utilizing LANDSAT TM data. In this study, distribution of Suspended Solid, Chlorophyll, Oil pollution and distribution of temperature were targeted. The results of these analyses indicate the possibilities of significant correspondence with actual water qualities and of important bases for selection of water monitoring site within the study area.

The work of "Preparative Field Inspection" means that the field survey conducted in Intensive Study Area at the 2nd work Stage to know the basic characteristics of the Arabian Gulf water. The actual work of this field survey was a set of measurement of water quality parameters by means of portable quality measurement meter and/or easy type water sampling. In some sites, visual observation of the seabed condition was also executed by diving with snorkel. The results of these measurement and observation provided useful and basic data to construct water quality monitoring plan of the 3rd work stage. This investigation also was very helpful for C/P of MEPA to understand the fundamental methods of water quality monitoring.

The work of "Monitoring Investigation" means that the water and sediment quality monitoring that was conducted in Intensive Study Area at the 3rd work stage. Installation of laboratory equipment, preparations of monitoring equipment and technology transfer about water monitoring to C/P of MEPA were conducted before to start the actual work. Actual monitoring work was conducted during the period from October to November, 2000 indicates various important results of quality about water and sediment pollution condition in coastal area of the Arabian Gulf.

Together with the results planned to be obtained during the period from June to July 2000, the detailed scientific analysis of these monitoring results was implemented.

The results analyzed were utilized for making the water quality monitoring plan in the whole Arabian Gulf area in the future.

On the following a couple of sections, the details of these three matters are described.

4.2 Satellite Image Analysis

4.2.1 Introduction

Satellites data are very widely used for the synoptic observations with high observational density over relatively large areas. The potential of satellite remote sensing for the monitoring of water quality has been long recognized. The present study used the LANDSAT Thematic Mapper (TM) satellite data at the 3rd and 4th Work Stages for providing a synoptic and quantitative overview of water quality in the Intensive Study Area of the Arabian Gulf.

The whole satellite data analysis was conducted in Japan at the 3rd Work Stage and maps at 1:500,000 scales were prepared for the distribution of suspended solids, chlorophyll a and oil pollution. Five TM scenes utilized were as, Path/Row: 165/040-041 - 20 Jan 1999, 164/041 - 12 Dec 1998, 164/042 - 12 Dec 1998, 163/042 - 21 Dec 1998, 163/043 - 03 Nov 1998. Results showed the variations for suspended solids, chlorophyll *a* and possible oily surface water micro-layers.

TM analysis was also conducted at 4th Work Stage at the Geographical and Remote Sensing Unit of the MEPA, Jeddah. Three TM imageries (Path/Row 164/041, 12 Oct 1999; Path/Row 164/042, 12 Oct 1999 and Path/Row 163/042, 21 Oct 1999) were utilized (data acquisition dates, Oct 12 1999 and 21 October 1999, coincided with the sampling duration of the water quality data) for the analysis and maps were prepared for the distribution of temperature, suspended solids, chlorophyll *a* and coastal areas of the Intensive Study Area.

The detailed background, methodology, results and discussions, conclusions and recommendations, reviewed literature etc., for the analyses are mentioned separately under Satellite Data Analyses for Work Stage 3 and Work Stage 4 sub-headings of this report.

4.2.2 Background

(1) LANDSAT/TM Satellite

The American Satellite, LANDSAT Thematic Mapper (TM) is designed to maintain fixed orbital paths around the earth with each path covered in 16 days at a standard altitude of about 705 km. One full LANDSAT scene is covered by 170 km (north-south) by 185 km (east-west) with spatial (ground) resolution of 30 x 30 m (except thermal-infrared range, i.e., band 6, which has a pixel resolution of 120m). The satellite crosses the equator from north to south on a descending orbital node at approximately around 09:45 a.m. local time on each pass. Each orbit takes nearly 99 minutes, and spacecraft completes just over 14 orbits each per day, covering the entire Earth (poles excepted) every 16 days.

TM data are available in seven narrow bands, i.e., three in the visible spectrum band [bands 1 (blue), 2 (green) and 3 (red)], three in the infrared zone (bands 4, 5 and 7) and one in thermal (emitted) infrared region (band 6). The descriptions of the seven sensors are mentioned in Table 4.2.1.

Table 4.2.1 LANDSAT's sensor description

TM Bands	Wavelength (micrometer, μm)	Resolution (m)	Coverage (km)
1	0.45 – 0.52 (blue)	30	185
2	0.52 – 0.60 (green)	30	185
3	0.63 – 0.69 (red)	30	185
4	0.76 – 0.90 (near-infrared)	30	185
5	1.55 – 1.75 (intermediate-infrared)	30	185
6	10.4 – 12.5 (thermal infrared)	120	185
7	2.08 – 2.35 (mid-infrared)	30	185

(2) Study Area Coverage

The four Full Scenes and one Sub-scene of the LANDSAT TM Satellite cover the Arabian Gulf coastal region (for the present Study).

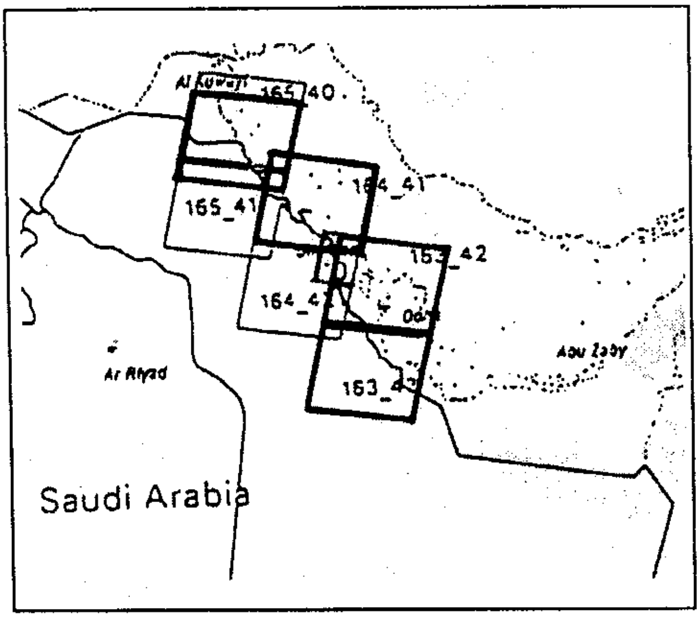

Figure 4.2.1 Study area coverage by LANDSAT/TM Satellite

Due to cloud cover and satellite recording problem the following TM's Path/Row and acquisition dates were selected and utilized to prepare the Mosaic Image and subsequent analyses in this Study (individual images are shown in Plate 1).

	Path/Row	Acquisition Date	Scene
1.	165/040-041	JAN 20 1999	Full Scene (50% South shift)
2.	164/041	DEC 12 1998	Full Scene
3.	164/042	DEC 12 1998	Sub-Scene (1/4 or NE of Full Scene)
4.	163/042	DEC 21 1998	Full Scene
5.	163/043	NOV 03 1998	Full Scene

(3) Analysis Procedures

The analysis procedures conducted in the present study is summarized as below:

LANDSAT/TM Data searching, selection and acquisition

⇩

Georeferencing and preparation of LANDSAT/TM Mosaic Image at 1:500,000 scale

⇩

Water Quality Analysis of the TM data and preparation of Maps at 1:500,000 scale

- Suspended Solids Distribution Map
- Chlorophyll Distribution Map
- Oil Pollution Distribution Map

⇩

Report preparation and utilization of the Maps for the monitoring plan

(4) Utilized Software and Map production

In order to process the LANDSAT/TM satellite data, ERDAS IMAGINE ver 8.3 (ERDAS IMAGINE Field Guide, 1997) was utilized. ERDAS IMAGINE is powerful Image Processing Software that provides innumerable solutions to the various users for different application purposes. Also, ARC/INFO ver 7.2, Geographic Information System software for geographic solutions and database management, was used for map layout preparation.

Once the data were analyzed by the image processing software, the prepared image files were converted as GRID files (it is a raster image file in ARC/INFO's format) and brought into the ARC/INFO's environment for map layout preparation. The maps were prepared at 1:500,000 scale and plotted by CalComp X2020 Plotter.

(5) Mosaic Image

The Mosaic Image was prepared by using bands 4, 3, and 2. TM's Band 4 (spectral range as near-infrared region, 0.76 – 0.90 μm), Band 3 (red spectral region, 0.63 – 0.69 μm) and Band 2 (green spectral region, 0.52 – 0.60 μm) were utilized to prepare the False Color Composite (FCC). TM's six bands have an improved spatial resolution of

30 x 30 m or (0.5 ha) and band 6 (thermal infrared) has a resolution of 120 x 120 m. In the present Study the ground resolution was re-sampled for 50 x 50 m during georeferencing for preparing the Image at 1:500,000 scale.

The FCC shows coverage of the Intensive Study Area and Target Marine Area for this project (Plate 2). The Intensive Study Area is covered by the TM data acquired on 12 December 1998 (Path/Row 164/041 and 164/042), as shown in Plate 3. The data acquisition dates are different for the remaining areas. This was due to presence of clouds and limitation of TM's data quality therefore, the best imageries of the nearest dates were acquired.

(6) FCC Interpretation

The brightness of the processed images was enhanced to highlight the sea water surface. The shallow water depth areas along the coast can be identified from the visual interpretation. The combination of bands 4, 3 and 2, senses peak chlorophyll reflection as red. The resulting red hues are easily discriminated by human eye. Water boundaries are defined clearer. FCC shows the sea water color variation near the coastal areas. The seawater color variation can be interpreted as the variation in the reflection and refraction characteristics due to water quality degradation along the Arabian Gulf. The coastal modifications by dredging or corniche developments can be clearly observed (Plates 2 &3).

The TM bands showed scan lines as noise in the images. Occasionally, images are corrupted by "noise" that is periodic in nature. The images were spatially filtered for reducing the noise and for improving the analysis results. However, the noises were unavoidable to be removed completely from the images.

(7) Interaction of Electromagnetic Radiation with Water

Unlike vegetation or soil, the majority of the radiant flux incident upon water is not reflected but is either absorbed or transmitted. Water absorbs near infrared and middle infrared wavelength strongly, (Figure 4.2.2) leaving little radiation to be either reflected or transmitted (Curran, 1985).

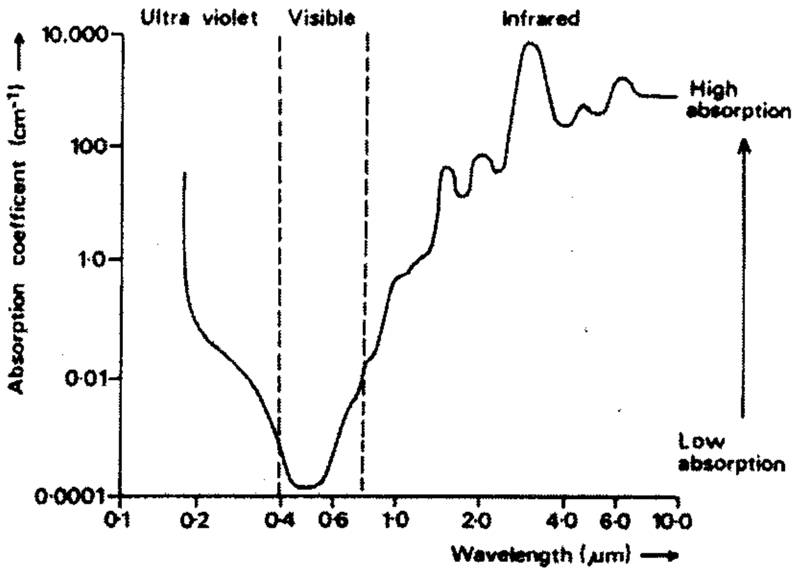

Figure 4.2.2 The absorption of electromagnetic radiation by seawater.

This results in a sharp contrast between any water and land boundaries as can be seen in a near infrared image of LANDSAT (Plates 1 to 3).

The factors that affect the spatial variability in the reflectance of a body of water are usually determined by the environment. The three most important factors are, the depth of water, the materials within the water and the surface roughness of the water. In shallow water some of the radiation is reflected not by the water itself but from the bottom of the waterbody. The three most common materials suspended in water are non-organic sediments, tannin and chlorophyll (< biblio >). The effect of non-organic silts and clays is to increase the scatter and reflectance, in visible wavelengths as can be seen for the coastal region. In agricultural scene the main coloring agent is tannin produced by decomposing humus; this is yellowish to brown in color and results in decreased blue and increased red reflectance. Water bodies that contain chlorophyll have reflectance properties that resemble, at least in part, those of vegetation with increases green and decreased blue and red reflectance. However, the chlorophyll content must be high before these changes can be detected. The roughness of water surface can also affect its reflectance properties.

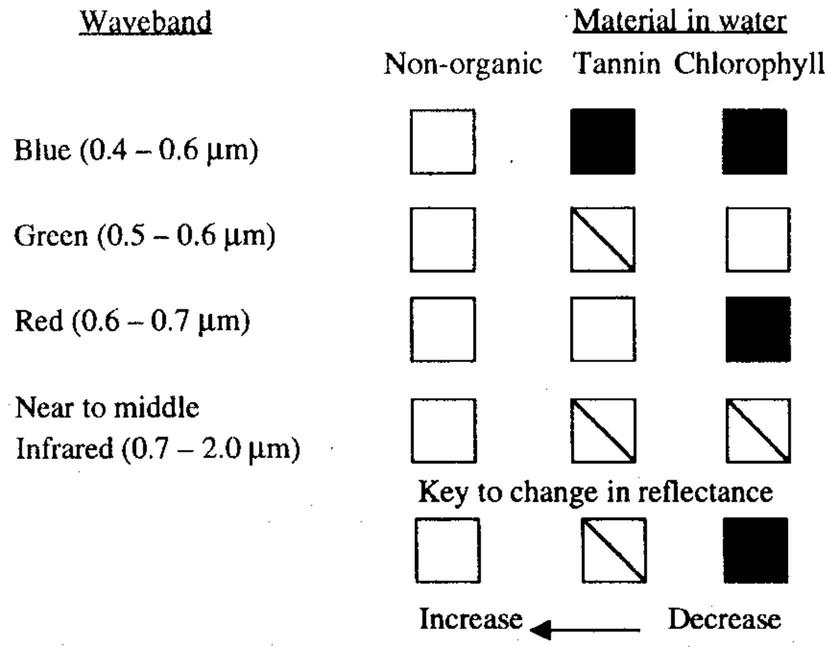

Figure 4.2.3 The relationship between the presence of materials within a water body and its reflectance in blue, green, red and near to middle infrared wavebands.

(8) Water Quality VS. LANDSAT Data – Literature Reviewed

1) Introduction

Water quality degradation is caused by organic waste, industrial discharge or oil spills. Sunlight entering a water body is subjected to change because of absorption, scattering and reflection, and the upwelling light carries information about water quality. For instance, the spectral nature of the light just above the surface of water body where chlorophyll concentration is high will be different from that reflected by suspended sediment with little sediment. Multispectral Scanner (MSS) and TM from the LANDSAT series of satellites have shown great potential in water resources assessment.

2) Suspended Solids

LANDSAT images provide a synoptic view of the coastal region and are ideal for mapping turbidity or suspended sediment distribution pattern. The satellite image from the ocean, in the visible bands, has its characteristics determined by the properties of light interaction with water and with its suspended and dissolved constituents.

An example of the wavelength relationship with the reflectance characteristics of the suspended solids is shown in Figure 4.2.4 (Ritchie et al. 1976). One can see that reflected solar radiation between 0.45 – 0.90 μm (micrometer) increased as the concentration of suspended sediment increased. The peak of reflected solar radiation shifted from 0.55 μm at low sediment concentration to above 0.60 μm at higher sediment concentrations. This kind of study indicates the feasibility of using LANDSAT data (Lo, 1986).

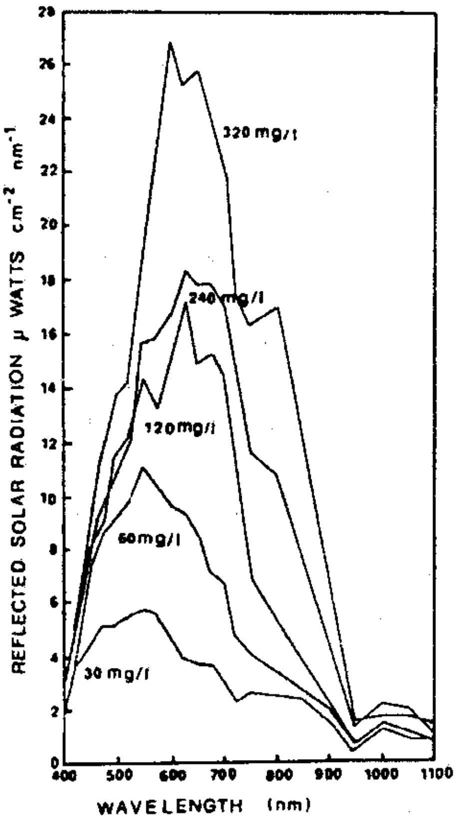

Figure 4.2.4 Reflectance characteristics at varying wavelength.

Since the launching of MSS of LANDSAT and Coastal Zone Color Scanner (CZCS) of NIMBUS Satellite in the '70s, many empirical studies have related water quality parameters and remote sensing data. For example, Klemas et al. (1974) related spectral responses of MSS Band 5 (red region, 0.60 – 0.70 μm), 80m resolution, with total suspended solids (TSS) and water circulation patterns. Saitoh et al. (1979) and Muralikrishna (1983) also used the MSS, Bands 4 (green region, 0.50 – 0.60 μm) and 5 to estimate suspended solids. Tassan (1981), working between radiance in the 0.59 μm and 0.68 μm bands to determine sediment concentrations

The remote sensing literature also shows a strong disparity between tests to identify the most appropriate bands or combinations of bands to study the same water quality parameters for different places with different satellite overpasses (Braga, 1990). This suggests the need for more field data acquired simultaneously with satellite imagery to assess the actual potential of remote sensing in water quality studies. Braga et al. (1993) conducted the principal component analysis (a method of digital data compression) of TM Bands 1-4 and reported the greatest amount of spectral information related to suspended sediments in Guanabara Bay, Brazil.

3) Chlorophyll *a*

Chlorophyll *a* is regarded as an important environmental parameter indicative of the water quality, nutrient contents and pollution effects in coastal zones, not simply as an indicator of water productivity. Changes in the color of the sea level patterns indicate the concentration of phytoplankton and sediment in the surface layer. Each phytoplankton pigment presents its typical reflectance curve. The pigment composition varies according to the phytoplankton species. A case study of the reflectance pattern of the phytoplankton is shown in Figure 4.2.5. For a given concentration of the yellow substance, sand and humus, five different values for the extinction coefficient of phytoplankton were plotted to show changes in reflectance for different chlorophyll concentrations. The values near 0.5 μm acts like a hinge; lower reflectance is observed in the blue, with increasing reflectance toward the green and red bands (Manual of Remote Sensing, 1983).

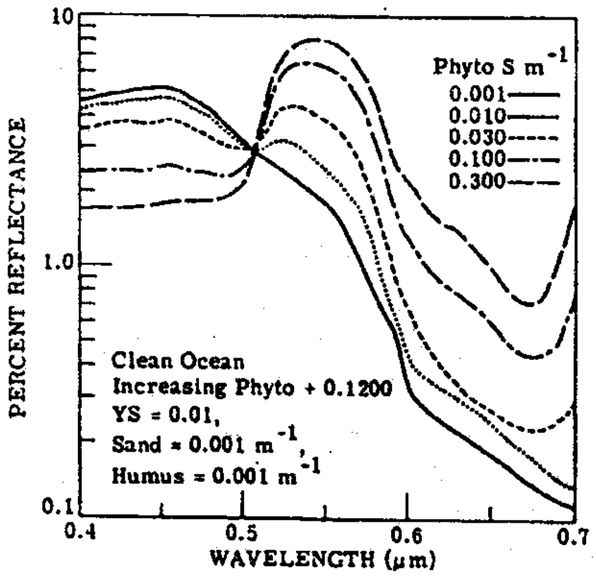

Figure 4.2.5 Reflectance characteristics of phytoplankton.

Numerous studies have been published mapping chlorophyll distributions, estimating chlorophyll concentrations and identifying algal species composition through the utilization of remote sensing. In 1972, with the LANDSAT program, there was an increase in the use of remote sensing data for estimating chlorophyll concentration. LANDSAT/TM data started to be considered for chlorophyll model development from 1986 (Grunwald et al., 1986; Ekstrand, 1991). Mizuo et al. (1993) observed chlorophyll *a* relationship with TM band 4 and other band combinations. Yacobi et al. (1995) applied a regression model to detect chlorophyll concentrations using high-spectral-resolution radiometer and LANDSAT/TM. Schooley (1996) utilized TM imagery combined with ground-truth data to model water quality in Barnegat Bay, USA and maps were produced for chlorophyll *a*, salinity and temperature. Allee and Johnson (1999) reported that TM band could explain a substantial proportion of variance within the measured chlorophyll *a* concentrations at the time of satellite flyby.

4) Oil Pollution

Oil spill monitoring is very important aspect considering the environmental sensitivity of the potential areas of impact. Multispectral data is widely used to map oil slicks that occur offshore due to leaks from oil-drilling platforms, pipelines, or accidental ship discharges. Satellites have shown the capability of monitoring large oil spills in marine waters. Studies have shown that oil-detection in general, several bands are useful but the ultraviolet and the thermal infrared regions consistently provide best contrast between oil and seawater.

The use of satellite remote sensing for oil pollution has been attempted several times. The slick from the 1978 IXTOC-I well blowout in Mexico was detected using Geostationary Operational Environmental Satellite (GOES) and also by NOAA and the LANDSAT satellite. A blowout in the Persian Gulf was subsequently detected. In both cases, the data was studied for several days to identify features associated with the known spill site. Several workers were able to detect the Arabian Gulf War Spill in 1991 (Fingas et al. 1998). The oil spill along the eastern coast of Saudi Arabia was detected and monitored during the early part of 1991 utilizing the mid infrared (1.55 – 2.35 μm) bands combined with the visible (0.45 – 0.6 μm) bands of TM sensors (Ibrahim et al. 1992).

4.2.3 Satellite Image Analysis in 3rd stage

(1) Suspended Solids Distribution Map

1) Methodology

The Principal Component Analysis (PCA) was conducted for total suspended solids (TSS) distribution. PCA is often used as a method of data compression. It allows redundant data to be compacted into fewer bands, i.e., the dimensionality of the data is reduced. The bands of PCA data are non-correlated and independent, and are often more interpretable than the source data (Jensen 1996). The TM bands 1, 2, 3 & 4 were subset for the PCA after the land had been separated by generation of mask derived from water classification on TM 4. Thus, the PCA was applied to TM bands 1, 2, 3, and 4 on the seawater only. The PCA Band 2 (PCAB2) was chose following the method of Braga et al., 1993. The resultant images were mosaiced for preparing the Suspended Solids Distribution Map at 1:500,000 scale (Plate 4). The subsequent quantitative analysis could not be performed due to lack of *in situ* measurements and laboratory analysis of water samples for the satellite data acquisition dates.

2) Results and Discussion for Suspended Solids Distribution

PCAB2 analysis showed the spectral information related to the water quality in the Arabian Gulf. The distribution was categorized to six levels. The red color indicates the highest and dark blue the minimum or negligible distribution level (red>orange>yellow>green>cyan>blue). The effects of clouds on the distribution can be also seen in the images (in NE for path/row – 165/049, NW for path/row – 164/041, Plate 4). The result shows the greatest amounts of suspended solids were concentrated near the coastal region. The shallow coastal depths have also reflected the high sediment concentrations.

High SS concentration was obtained as 12 mg/L for T7 site (conducted by the Study Team in October – November 1999, see section 4.3) and the TM analyzed results have also indicated the Red color. The SS was 2 mg/L for the control site J1 and the color is indicated as Cyan. For T4 the measured SS was 9 mg/L and image shows Orange color distribution. Other sampling points have also shown agreeable results. We can observe the analyzed TM images in accordance to the measured *in situ* data although the sampling dates and the TM data acquisition dates are wide apart.

(2) Chlorophyll Distribution Map

1) Methodology

In the present project the chlorophyll distribution map was prepared by utilizing the TM 4. The TM Band 4 lies in near infrared region (0.76 – 0.90 μm), has the features of complete absorption by water, high land water contrasts and very strong vegetation reflectance. The TM band 4 was subset out of the TM's 7 bands and level slice was performed for each image. Level slicing is an image enhancement technique whereby digital numbers distributed along the x-axis of an image histogram are divided into a series of analyst-specified intervals or "slices" (Lillesand and Kiefer, 1994). The TM 4 data have been level sliced into multiple levels for determining the chlorophyll distribution for each images and finally five categories were established and mosaicked for preparing the chlorophyll distribution map at 1:500,000 scale. The red color indicates the highest and dark blue the lowest distribution (red>yellow>green>cyan>blue). Subsequent quantitative analysis could not be carried out due to lack of *in situ* measurements and laboratory analysis of water samples for the satellite data acquisition dates.

2) Results and Discussion for Chlorophyll Distribution

The distribution was categorized to five levels. The red color indicates the highest and dark blue the least distribution level (red>yellow>green>cyan>blue). The effects of clouds on the distribution can be also seen in the images (in NE for path/row – 165/049, NW for path/row – 164/041, Plate 5). The chlorophyll distribution was observed to concentrate along the nearest coastal areas. Less distribution of the chlorophyll can be attributed due to presence of higher concentration of the suspended solids, especially when both materials are spatially associated (Alfoldi, 1982). The *in situ* sampling (conducting during October – November, 1999) analysis results showed very less chlorophyll *a* detection for J4, J6, J7 and other areas. The TM analyzed images also show similar results (Cyan color distribution, Plate 5) although the date of satellite flyby was wide apart.

(3) Oil Pollution Distribution Map

1) Methodology

The TM Band 5 was considered for this analysis. The TM band 5 ranges from 1.55 - 1.75 μm (intermediate infrared wavelength region). The TM Band 5 was subset out of the 7 bands and was density sliced into 4 classes (red>yellow>cyan>blue) to obtain the variation of the digital values that indicate the possible oil pollution distribution in the study area (NASDA/EORC, 1997). Images were mosaicked (Plate 6) and map at 1:500,000 scale was prepared. The subsequent quantitative analysis could not be performed due to lack of *in situ* measurements and laboratory analysis of water samples for the satellite data acquisition dates.

2) Results and Discussions for Oil Pollution Distribution

The distribution map shows minor oily surface water micro-layers variations. If there is an apparent oil spill in the ocean, the pollution can be easily detected on the TM images. It seems that there was no oil spill on the date of TM data acquisition and therefore no apparent variation was observed for the analyzed TM images. The results of the *in situ* water quality sampling conducted during October – November 1999 did not show the presence of oil and grease for majority of the sampling sites in the Intensive study area, showing the agreement with the analyzed TM imageries. It should always be remembered however, that the oil spills are unique and often idiosyncratic, and therefore some spills will be far more amenable to detection by TM than others.

4.2.4 Satellite Image Analysis in 4th stage

The LANDSAT Thematic Mapper (TM) satellite image analysis was performed at the Geographical and Remote Sensing Unit of the MEPA, Jeddah (21 June to 12 July, 2000) for preparing the distribution maps of the temperature, suspended solids, chlorophyll and coastal areas of the intensive study area. The general approach involved the acquisition of LANDSAT TM data (coincided with the sampling duration of the water quality data), followed by extraction of digital numbers (DNs) from TM Bands, development and verification of correlation of selected water quality variables to the spectral data, application of the models to the entire intensive study area, and the production of color coded resultant images, each depicting the distribution for the selected water quality variable. Three TM scenes – Path/Row 164/041, 12 Oct 1999, full scene; Path/Row 164/042, 12 Oct 1999, sub-scene; and Path/Row 163/042, 21 Oct 1999; were utilized for the analysis.

The geo-referencing, re-sampling (25m resolution/pixel) and initial spectral enhancements of the TM data were performed in Japan and data were brought to the KSA for the sea water quality analysis in MEPA, Jeddah. The data were loaded to the hard disks of the MEPA's workstations and the following analyses were carried out by the ERDAS IMAGINE image processing software. Plate 7 shows False Color Composite (TM Bands 4:3:2) coverage of the Intensive Study Area.

(1) Thermal Distribution

Monitoring of sea surface temperature is one of the most common applications of satellite remote sensing. The temperature distribution was performed for the first time in the present project utilizing appropriate TM's information.

1) Methodology

Sea surface temperature distribution was carried out by utilizing TM Band 6 (wavelength 10.4 to 12.5 micrometer, thermal infrared region) for the study area. Band 6 was a subset of the TM's 7 bands and image slicing was performed for each image. The Digital Numbers (DNs) of Band 6 are related to the thermal radiation. The DNs and corresponding temperatures were established (referring the conversion chart of the Remote Sensing Technology Center, Tokyo) for the temperature distribution of the intensive study area. Five categories for the temperature distribution were created for individual images. The images Path/Row 164/041 and 164/043 were mosaicked as both belonged to the same acquisition date, i.e., 12 October 1999. Image slicing, color-coding, recoding, mosaicking and statistical filtering were performed for the final map preparation. Plate 8 illustrates the thermal distribution coverage for the intensive study area.

2) Results and discussions

The temperature distribution for Path/Row164/041-042 ranged from a minimum of 23.5°C to a maximum of 30.6°C. For Path/Row 153/042 the range varied from 23.5 to 26.9°C. The overall temperature range of 26.5 to 27.5°C was observed from northeast (NE) to southern regions. Small patches of higher temperatures were distributed particularly in shallow areas and along the vicinities of the coastal regions where more industrial and residential activities are located (e.g., Jubail shared outfalls, SAFCO outfall etc.).

(2) Suspended Solids Distribution

1) Methodology

The laboratory analysis results of the seawater sampling, conducted during the period October 16 to November 8 1999, were utilized for the quantitative analysis of the suspended solids distribution. The digital values were extracted from TM Band 3 (0.63 to 0.69 micrometer wavelength range) for the satellite flyby sampling points of the intensive study area, by referring to the Global Positioning System (GPS) observations. Total suspended solid (TSS) values were correlated with the DNs ($r = 0.82$, standard error of estimate = 1.389; some outlying points were dropped to achieve this value) and distributions were applied for the whole area. Image slicing, color coding, recoding, mosaicking and statistical filtering were performed for the final map preparation.