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The Environmental Impacts of the Gulf War 1991

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IIASA

Cover Photo:

Over 900 oil wells in Kuwait were damaged by the retreating Iraqi forces in February-March 1991. About 600 of these wells caught fire.

Photos by Olof Lindén

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Abstract

The environmental consequences of the Gulf War in 1991 affected the air, the marine environment, and the terrestrial ecosystem. Various scenarios and forecasts had been made before the war about the possible and probable impacts under different conditions. The follow-up studies have showed a rather different picture than what had been forecasted. When considering the various aspects of air and atmospheric pollution, in brief summary, the following observations have been made:

Early in 1991 more than 800 oil wells were blown up, of these more than 600 caught fire and burned with flames and about 50 wells gushed oil onto the ground. During the period up to October 1991 all the wells were caped. The maximum amount of burnt oil and gas in the oil fires was about 355 000 tons and 35 million m^3 respectively per day. The sot emissions for the burning oil and gas has been estimated to about 20 000 tons per day and the total SO_2 emission about 24 000 tons per day. The CO_2 emission from the burning oil and gas in Kuwait has been estimated to about 130 to 140 million tons corresponding to 2-3% of the global annual anthropogenic contribution from the use of fossil and recent fuels and only 0.1% of the total global CO_2 emission. Levels of particles in the air a few kilometers from the burning oil fields was in the order of about 10^5 per cm^3. This corresponds to 10% of the global contribution from anthropogenic burning of recent and fossil fuels. Most of the soot particles accumulated at altitudes between 1000 and 3000 meters and very little contamination reached higher than 5000 meters. As a result the soot did not spread over large areas but fell out with rain and dew mostly over the northern Arabian Peninsula. The high volume of particles in the air had a very pronounced effect on the climate in Kuwait and in the neighboring countries. Temperatures were up to 10 degrees C lower than under normal years. Soot and oil covered extensive areas in Kuwait, northern Saudi Arabia and the Gulf. The vegetation as well as wildlife was exposed to this fallout but no or very scattered information is available about environmental aspects.

The oil from the oil wells formed networks of rivers and lakes on land. The total volume of oil in these lakes and rivers has been estimated to between 10 and 20 million tons. During 1991, up to 200 km^2 of ground was covered with oil forming about 250 lakes. In 1992 the figure had decreased to about 50 km^2, partly due to weathering, penetration of oil into the ground, coverage of oil by dust and sand, and physical removal. The oil has subsequently penetrated the ground to varying depth, depending on the nature of the underlying soil. The total area of oil lakes calculated based on satellite image in 1998 was about 24 km^2. However, at that stage much of the surface area of the oil lakes were covered by sand and could hardly be observed from the sky.

The *marine environment* was exposed to large quantities of petroleum hydrocarbons, the volume of the spills has been estimated to between 1 and 1.7 million tons. The oil was released from tank farms on land (Al Ahmadi North), oil loading

terminals (Sea Island and Mina Al-Bakr (Iraq)) and from oil carriers anchored along the Kuwait coast. The spill was broken up into several smaller spills which contaminated most of the Saudi Arabian coastline About 700 km of Saudi Arabian shoreline consisting of sand, gravel, wetlands, lagoons, and muddy tidal flats, sometimes covered by vegetation was contaminated. The oil was deposited on the tidal flats and a total the surface area of about 34 km2 was contaminated. Some oil ended up on the beaches of Kuwait, Iran, Bahrain and Qatar but generally these countries were less affected. The oil on the Saudi Arabian coastline ended up in shallow lagoons, wetlands and flats covered with vegetation. Here the oil caused considerable damage caused primarily by the physical characteristics of the oil on the vegetation and on animals in the intertidal zone. Hence most of the mangroves and marshes in the wetlands along the affected coast was destroyed by the oil. Fifty to 90% of the fauna of these areas, mainly crabs, amphipoda and molluscs, were also killed by the oil. Already within a year natural clean-up processes had removed most of the oil from hard surfaces and decreased the quantities considerably in areas with sand and mud. About three years after the spill most of the fauna had re-colonized the lower sections of the beach, and the recovery on the upper sections was underway. About 10 years after the spill, weathered and underground oil were still present on some beaches.

The large-scale clean-up that was carried out after the spill in many areas did contribute to increasing the damage and spreading the oil into previously unaffected areas. Studies from different subtidal areas along the Saudi Arabian coast on sand, mud and rock bottoms and in sea-grass beds showed minor or no effects at all among the fauna and flora at 1 to 6 meters depth and deeper areas. Several investigations were carried out to study the impact on the coral reefs along the coast but these studies did not reveal any significant effects, particularly in the reefs off the Saudi coast. Also the fish fauna appeared to have survived intact.

About 75 to 80% of the sun’s radiation was absorbed and the remainder was scattered by the smoke in the super composite plume and this resulted in a drop in the temperature by up to 10°C in Kuwait and the northern Saudi Arabia. Also as far away as 250 km from the burning Kuwaiti oil fields a reduction in mid day temperature of 5-8°C was recoded. Also seawater temperatures in the Gulf were considerably lower during 1991 as compared to previous years. This drop of seawater temperature during spring-summer period of 1991 was considered more damaging to fish and prawns than the oil spills.

Seabirds and waders were affected by direct oiling of feathers and due to intake of oil primarily through preening. It has been estimated that between 22 and 50% of the populations of several species of cormorants and grebes died as a result of the spill. Investigations of the presence of waders on the shores made during the acute phase of the war a reduction by almost 100% and most of the birds found were contaminated by oil. It was estimated that about 100 000 waders were killed directly or indirectly by the oil spill in 1991.

Investigations of the populations of marine turtles showed that green turtles nested at normal rates and with a hatching success similar to the figures for the years previous to the spill. For hawksbills the number of nests were normal but the hatching rate was much lower than normal.

Approximately 50 dugongs and several times as many dolphins were found dead on the beaches of Saudi Arabia after that spill.

In total over 84,000 tons of bombs were dropped over an area of about 4,000 square miles during 43 days of war. The military casualties and the allied side was 149 dead and another 513 wounded. In the years after the war between 50 and 100 allied soldiers were killed in connection with mine clearance. The total losses of Iraqi solders were much higher, probably more than 100,000 during 43 days of war. Nearly 25,000 died during the mass retreat. In addition at least another 100,000 Iraqi military were wounded, the majority of whom later died due to lack of medical facilities and medicine.

Between 400 and 600 Kuwaiti civilians were killed directly during the war. In addition an estimated about 2,000 died due to consequences of the war. Between 15,000 and 16,000 civilians spent time in prison during and after the war. In addition there have been more than 1,500 civilian mine and ammunition victims in Kuwait since August 1990. Furthermore a large portion of the Kuwaiti population suffered various psychosomatic disorders, so called Post-Traumatic Stress Disorder (PTSD) several years after the war. Another consequence of the war is that crime and violence has become more common in Kuwait.

Between 2,500 to 3,000 Iraqi civilians died directly as a result of the allied bombardment. However, Iraqi civilians suffered much larger casualties as indirect consequences of the war during the period 1991 – 2001. Figures are not known but several hundred thousand civilian, including infants and children, have probably died due to the lack of medicine, hospital supplies, and medical services. Other studies indicate that more than 46,900 children under five years age died between January and August 1991 due to the war and its aftermath. In addition about 100,000 Kurds in the north and Shiites in the south of Iraq died and many more suffered from heavy repression in the civil unrest immediately after the war. Other reports indicate increased child mortality among children in Iraq, in excess of 40,000 per year during the period 1992-1998.

Preface

When Sadam Hussein ordered the Iraqi invasion of Kuwait in August 1990, the world for the first time was facing the threat of serious environmental consequences as a main weapon by one party in a military conflict. This threat was an important element in the discussions how to prevent a dictatorial regime from threatening its neighbors and possibly the entire world.

From the invasion till the start of the allied bombardment there was an intensive debate in large parts of the world about the future consequences of the conflict: there were theories presented forecasting global climate impacts such as the "atomic winter" scenarios, via effects on the precipitation and the monsoons on a regional scale, to dramatically increased incidences of cancers throughout the Middle East. What did in fact happen?

In the present volume, the authors tries to summarize the findings from research and monitoring activities in several countries during the 10 years after the war. Two authors (Olof Lindén, Arne Jernelöv) visited the area in connection with final part of the war. They made observations in large parts of Kuwait and Saudi Arabia and have been revisiting the region frequently the following years. These observations together with a large volume of other published and unpublished information have been used in the present report. The actual environmental impacts of the war proved to be quite different from those anticipated at the onset of the conflict. Climate effects did occur but were localized and short-term. Despite the very large volume of oil that ended up in the Persian Gulf, there were few long-term effects in the marine environment. Long-term impacts have been found in bird populations and on the terrestrial ecosystem and well as on the surface structure of the desert. Quite a large number of questions remain unanswered: what happened to the PCB in hydraulic oils in military material and vehicles, how much halones were used by the air force, and what damage was caused as a result of the bombs over the chemical industries in Iraq? The human suffering caused by the war was extensive. Although the Kuwaiti population was affected, by far the larges difficulties affected the Iraqi civilian society, both due to the war itself, but primarily due to the sanctions following the war.

About the Authors

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Introduction

War is, almost by definition, destructive; not only to human societies but also to the environment. Even without actual combat, any large accumulation of military forces in an area will cause considerable damage to the environment as military preparation generates pollution and destroy the natural vegetation and consumes resources. However, attempts to damage the environment and natural resources as a tactic of war against the formal enemy or as a mean of instilling terror in the general public have been quite common throughout history. For centuries, Russian armies have applied the strategy of scorching their own territory in order to prevent invading armies from gaining valuable resources. Combatants may also, for tactical purposes destroy physical infrastructures, with obvious environmental consequences. Some examples are the destruction of dams or dike systems to cause flooding, or destruction of industrial facilities like nuclear reactors, chemical factories, or petroleum production facilities. During World War I, in the autumn of 1916, the British military blew-up Romanian oil fields to prevent the Central Powers from capturing them. About seventy oil wells and refineries were set on fire. It has been estimated that 800,000 tonnes of oil was lost and it took the Germans five months to extinguish the fires. In Vietnam during the 1960s and 1970s, the US and South Vietnamese armed forces used herbicides to defoliate trees and bushes in order to deny the Vietnamese guerillas cover and to separate them from the local population. As a result, vast areas of tropical forests, mangroves and agricultural lands were affected by herbicides and white phosphorus. Through these actions highly toxic and long-lived chemical contaminants such as the so-called Agent Orange were spread over extensive areas. More recently, Colombian rebels have been detonating petroleum pipelines, spilling millions of barrels of crude oil into the rivers, contaminating drinking and irrigation water, killing fish and other wildlife and contributing to air pollution (Bruch et al., 1998).

The 1990-1991 Gulf War, which started with the invasion of Kuwait by Iraqi forces in August 1990, demonstrated the ways in which the technologies of war and industry can be used to wreak widespread environmental destruction. Iraqi troops detonated more than 700 Kuwaiti oil wells and released about 10 million barrels of Kuwaiti oil into the Arabian Gulf (Tawfiq and Olsen, 1993; Al-Hammadi and Al-Abdalrazaq, 1995). The present report is an attempt to collate the available information about the environmental impacts of the 1990-91 Gulf War. It is based on a number of sources, published as well as unpublished or available only in co called "gray" literature. The authors (Olof Lindén and Arne Jernelöv) also made a number of observations ourselves during several visits to the area, the first visit in the immediate aftermath of the war.

1. The Links Between Natural Resources and Armed Conflicts

Armed conflicts and natural resources can be directly related in two main ways (Le Billon, 2001). Firstly, armed conflicts are motivated by the wish to come in control of resources, and secondly natural resources are in reality directly contributing to the war by financing the war effort. Although few armed conflicts so far were initially motivated by a struggle over the control of natural resources, politicians and military strategists often integrate natural resources into the political economy that is the backdrop against which the plans for war are drawn.

Today more than ever population pressure and growing resource needs throughout the world are increasing the risk for conflicts (Myers 1993; Meyers and Kent, 1995; Kaplan, 1996). Until recently, at least in the political propaganda, the international conflicts were primarily governed by political and ideological considerations. The wars of the future will, according to many experts, be largely fought over possession and control of vital economic goods, especially the resources needed for the function of modern industrial societies (Klare, 2001). Water and oil, because of their critical roles in sustaining human life and economic activity, are the resource that are most likely to ignite conflicts between states today. The Old Testament, as well as many other sources of information from early civilizations contains numerous allusions to droughts and a limited capacity to produce sufficient quantities of food and the resulting conflicts between different groups. The Old Testament tells of water-disputes between the city-states of Lagash and Umma in the Tigris-Euphrates basin and, since then, conflict over water has triggered many wars in the Middle East. Because early civilizations in that region depended for their survival on a complex system of dikes and canals, such works were often the target of attack during outbreaks of combat. Although often overshadowed by other events, conflict over water has also erupted during the modern era. In the Middle East, water is scarce and widely shared by countries with enormous economic, military, and political differences (Gleick, 1994). Fighting over control of the tributaries of the Jordan River, for example, was one often-overlooked factor behind the Arab-Israel War of 1967. Iraq and Syria almost went to war in 1975, when Syria began filling up Lake Assad and reduced the flow to Euphrates River as it emptied into Iraq. Jordan, Israel and Palestine (the Gaza Strip and the West Bank) are some of the most water-stressed areas of the world. There are few economically or politically acceptable alternative sources of supply. However, the situation is similar in several other areas of the world and the gap between water supply and demand is increasing. By 2050 it is estimated that 25% of the worlds population will live in areas affected by chronic or recurring shortages of fresh-water (UNESCO-WWAP, 2003). Thus, the temptation to use water for political or military purposes has often proved irresistible. As water supplies and delivery systems become increasingly valuable in water-scarce regions, their value as military targets increases.

The Gulf War in 1990/1991 underscored the many connections between water and conflict. During this war, water and water supply systems were targets of' attack, shared water supplies were used as political instruments, and water was considered a potential tool of warfare. The dams, desalination plants, and water conveyance systems of both sides were targeted for destruction. The retreating Iraqis destroyed most of Kuwait's extensive desalination capacity. Oil spilled into the gulf threatened to contaminate desalination plants throughout the region. Another example was the water supply and sanitation system of Baghdad and Basra, which were targeted during the aerial bombardment of Iraq.

1.1 Can the Environmental Benefit from War?

Certain types of military conflicts may in fact be positive for the environment, at least in the short-term and under certain conditions. Demilitarized zones (DMZs) are often beneficial for biodiversity: an outstanding example of this is the DMZ of the Korean Peninsula (McNeely, 2000). This zone has become a haven for rare and endangered flora and fauna and now constitutes a unique natural and preserved wildlife habitat ranging across the entire landscape of the Korean peninsula. A similar situation occurred in the demilitarized zone between the Eastern Block and Western Europe from the Second World War till early 1990's. In this zone the environment was left undisturbed and a long corridor of European natural forest ecosystem developed, an environment that functioned as a refuge for fauna and flora that was under increasing pressure from practically everywhere else. Other more bizarre examples of the positive impacts of war are to be found with those species that feed on battlefield dead. It was reported that number of tigers was increasing in the jungles of Southeast Asia during the Vietnamese War and that sharks entered the rivers - unusual territory for them - to feed on dead soldiers during the Iran-Iraq War. When the German navy, during the Second World War, forced the closure of the North Atlantic fisheries, the fish-stocks recovered dramatically and the catches after the war were larger than ever before. During the Central American wars of the 1980s, trade in gold, mahogany, cedar, animal skins, sea turtles, shrimp, and lobster nearly stopped: hunting decreased, and the populations of several endangered species increased dramatically (Brauer, 2000). However, the general picture is unfortunately the opposite. In wars also the environment is suffering and there are numerous examples of animals and even entire ecosystems that have been completely destroyed during armed conflicts.

1.2 "The Law of War"

For as long as the environment has been used as a weapon of war, moral and religious rules and codes have sought to prevent or minimize the environmental impact of wartime actions. An early example of this can be found in the bible when Deuteronomy forbade the destruction of fruit trees during siege of an enemy city (Deuteronomy 20:19-20). Although the definition of the environment in the old days was considered from a rather narrow and anthropocentric perspective, it was common for much of the Judeo-Christian communities. Similarly, the Koran prohibits the destruction of any plants or trees in wartime. In the Buddhist and Hindu traditions there are rules, both for peacetime and during war, about avoiding unnecessary harm to the environment and to show respect to the environment in a broader sense. Many of these religious norms have been incorporated into current international law.

Today there are a number of laws and regulations that in various ways are meant to constrain wartime actions which might cause unnecessary damage including environmental impacts. This legal framework is an assemblage of declarations, conventions and treaties aiming to regulate the various aspects of warfare. The essential principals of these laws and regulations are discrimination (carefully determining targets, weaponry, and tactics), necessity, proportionality, and avoiding unnecessary suffering and damage including environmental destruction. Among the first regulations on warfare was the 1868 St. Petersburg Declaration (Declaration Renouncing the Use, in Time of War, of certain Explosive Projectiles. Saint Petersburg, 29 November/11 December 1868) which focused on preventing unnecessary suffering to people and unnecessary harm to their property. The declaration stated that; “the only legitimate object which States should endeavor to accomplish during war is to weaken the military forces of the enemy”.

In the 1907 Hague Convention (Hague Convention IV (18 October 1907) Convention Respecting the Laws and Customs of War on Land, Articles 1 – 56, Entry into Force: 26 January 1910) baselines are provided for limiting methods of warfare: “The right of belligerents to adopts means of injuring the enemy is not unlimited” (article 22). Several other provisions of the convention are relevant to certain instances of environmental damage. It is especially forbidden “to destroy or seize the enemy property, unless such destruction or seizure be imperatively demanded by the necessities of war” (article 23(e)). The convention also forbids the use of “arms, projectiles, or material calculated to cause unnecessary suffering” (article 23(g)).

The 1925 Geneva Protocol on gas and bacteriological warfare (Protocol for Prohibition of the Use in War of Asphyxiating, Poisonous or other Gases, and of Bacteriological Methods of Warfare, done at Geneva, June 17, 1925, entered into force, Feb. 8, 1928) provides one basis for asserting the illegality of forms of chemical warfare having a harmful effect on the environment.

The Four 1949 Geneva Conventions are concerned above all with the task of protecting victims of war. However, one of these conventions, The Civilians Convention (Convention Relative to the Protection of Civilian Persons in Time of War, done at Geneva, Aug. 12, 1949, entered into force Oct. 21, 1950). contains a large number of provisions relevant to the protection of the environment.

The 1977 Protocol Additional I to the Geneva Conventions (Protocol Additional to the Geneva Conventions of August 12, 1949, and Relating to the Protection of Victims of International Armed Conflicts (Protocol I) (Geneva, June 8, 1977, entered into force, Dec., 1978) is the first law of war convention to specifically protect the environment: “Methods or means of warfare which are intended, or may be expected, to cause widespread, long-term and severe damage to the natural environment” (article 35(3)) are prohibited.

The 1976 Environmental Modification Convention (ENMOD) (Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (done at New York, Dec 10, 1976, entered into force, Oct. 5, 1978) focuses more on preventing use of the environment as a weapon, and has little or no relevance to most instances of damage to the environment during war.

In addition there are a number of relevant domestic and international laws that are applicable to wartime environmental damage. However, domestic environmental law usually relates to peacetime military activities and is therefore of rather limited relevance. Increasingly, international environmental treaties, such as the Rio Declaration, condemn wartime environmental damage.

To conclude the protection of the environment during armed conflicts today rests primarily upon two pillars: on the one side are the conventions, declarations and treaties forming what may be called ”The Law of War”, and on the other side are the peacetime rules for environmental protection (Vöneky, 2002). Several experts and politicians have argued that this is not enough and that a separate convention is needed. This could be a fifth Geneva Convention designed to protect the environment during wartime. The events of the 1990-1991 Gulf War drew attention to the apparent absence of a simple, formally binding, set of rules about the impact of war on the environment. As Iraq had not ratified the 1976 Environmental Modification Convention (ENMOD) and had not signed or ratified the 1997 Protocol Additional I of the Geneva Convention, there were little room for legally pursuing the environmental destruction, even though the war of 1991 may have been more destructive to the environment than any war in history. Iraq was accused of deliberate environmental degradation both because of the deliberate release into the Gulf of the largest oil spill in history, and due to the blow-up of the oil wells in Kuwait. Most experts consider that these acts could not be justified by military necessity. Therefore Iraq committed crimes according to the Hague and the Geneva Conventions. These conventions are considered customary international law and therefore the entire international community, including Iraq, are bound by them. (Bruch et al., 1998; Roberts, 2002)

1.3 Compensation for Environmental Damage: The Case of Kuwait versus Iraq

United Nations Security Council Resolution 687 (1991) reaffirmed that Iraq “is liable, under international law, for any direct loss, damage, including environmental damage and the depletion of natural resources, or the injury to foreign governments, national and corporations, as a result of Iraq’s unlawful invasion and occupation of Kuwait”. Having reaffirmed such liability, the Security Council Resolution 692 (1991) established the United Nations Compensation Commission (UNCC) as a subsidiary body under the Security Council, to process claims and pay compensation for losses resulting from Iraq's invasion of Kuwait. Compensation is payable from the UN Compensation Fund, also established under Security Council Resolution 692. Kuwait has submitted five claims to the United Nations Compensation Commission concerning; (1) damage to groundwater resources; (2) damage related to the formation of lakes of oil in the desert; (3) damage to terrestrial resources; (4) damage to marine and coastal resources; and (5) damage to public health (Dickie and Gerking, 2002). The claimed ecological damage focus on measurable clean-up and remediation costs, and not on claims for lost environmental values such as decreased productivity or biodiversity.

After the war, Iraq was nearly bankrupt and the country’s future oil revenue seemed to be the best source of hard currency. Initially the plan was that a percentage of Iraq’s future oil revenue would go to pay for the damage it caused through its invasion and occupation of Kuwait. As the Iraqi regime remained in power and economic sanctions continued for longer than originally envisioned, a scheme was introduced 1995 which allowed Iraq to sell oil on the world market under the so-called “oil-for-food programme”. Basically the plan was to allow Iraq to sell pre-determined quantities of oil, while the UN received the revenue from these oil sales and allowed Iraq to repatriate the proceeds only in the form of food purchase and medicine. In the process, the UN diverted 25% of the proceeds to the Compensation Fund. The Commission uses these funds to pay compensation to victims of the Iraqi aggression.

Since 1991, UNCC has received approximately 2.6 million claims seeking compensation in excess of USD 300 billion. Although the overwhelming majority of the 2.6 million claims filed with the Commission have been resolved, the largest claims still to be considered by the UNCC include those for environmental damage (UNEP, 2002). Therefore, the United Nations Environment Programme and UNCC agreed on a cooperation to facilitate the tracking of environmental monitoring and assessment projects in the Arabian Gulf region. The agreement will make UNEP a provider of environmental database services for UNCC. The database will contain information from claimant governments regarding the monitoring and assessment projects, as well as available remediation methods and technologies, along with environmental policies and legislation. The database-project will cover a two-year period starting in August 2002, at a yearly cost of USD 1 million.

1.4 Assessing Environmental Impacts of War

It is often difficult to make more precise environmental impact assessments in connection with wars. The impacts are often multi-dimensional, and they also often have repercussions in areas a long distance away from those of concentrated battle and over prolonged periods of time, long after war has ended (Biswas, 2002). Land is affected both by direct war action and by military preparations. Missiles, bombs and other sorts of ammunition contribute to the formation of craters, compaction and erosion, and soil contamination by toxic and hazardous deposits. Land use patterns often change over prolonged periods of time due to the continuous presence of landmines and other debris from war. Contamination of both surface and groundwater is also a common result of various types of warfare. Use of biological, chemical, and nuclear weapons contribute to long-term water pollution, resulting in health hazards for humans and associated ecosystems. Water distribution and sewer systems, as well as water and wastewater treatment plants, are often strategic targets, or may be hit by accident. The indirect costs of such destruction to human health are often simply unknown and very difficult to calculate. Serious air-pollution often occurs as a result of the use of biological, chemical, and nuclear weapons, but also from emissions from the vehicles and other equipment used during routine war activities and military operations. Resource depletion is another important environmental impact of war and even during peacetime, military use of energy and non-renewable resources is substantial. War efforts also generate vast quantities of hazardous materials and the production, maintenance, storage, and use of weapons alone generate great varieties and tremendous quantities of these wastes.

The methodologies for assessing the environmental impacts of war are basically the same as those employed during peacetime. Many of the standard ecological monitoring tools can be useful for determining local, air, water, and soil pollution. For larger-scale impacts, aerial reconnaissance and remote sensing can be useful. The most far-reaching is however the environmental impact assessment (EIA) process itself.

Nevertheless, experience has shown that the long-term reliability of most environmental assessments is problematic at best (Brauer, 2000). In many instances there are no, or only insufficient, baselines, which means pre-war data, to compare war-induced environmental effects. For instance, while it is possible to determine how the Kuwaiti desert environment is affected by oil pollution from the gushing oil wells, it can be difficult to distinguish the environmental impacts of pre-war petroleum industry from wartime activities (Bruch et al., 1998).

It is the predictions of long-term environmental impacts that often have been proven to be surprisingly inaccurate, particularly when common practices are found to have severe and unpredicted negative impacts. For example, Agent Orange was considered harmless to human health until scientists started to understand the impacts of dioxins, which were contained in Agent Orange, but by then it was too late. The Gulf War provides another good example of the difficulties of predicting the environmental impacts of war. Several of the predictions during and after the war were overestimated. For example, the oil fires did not increase global warming or affect global climate because of the smokes low altitude and its short residence time. Neither did the ground-level concentrations of nitrogen oxides, carbon monoxide, hydrogen sulfide, and ozone exceed the local standards of Kuwait and Saudi Arabia. Yet, even if no reliable scientific data are presently available to indicate that the Kuwaiti oil fires had many long-range and long-term effects on the global climate, no one can question their local, and even regional, impact (Biswas, 2002). The long-term impacts of the soot and oil deposition over much of Kuwait and northeastern Saudi Arabia on soil, water, and vegetation are simply unknown at present and even if the ecosystems in Kuwait have proven to be remarkably resilient, the fires have unquestionably impacted on the terrestrial biosphere. Some World War I battlefields remain barren eighty years later and many Vietnamese still have elevated blood levels of dioxine (Bruch et al., 1998).

2. Environment in Arabian Peninsula and Gulf

2.1 Climate

Kuwait, northern Saudi Arabia, and southern Iraq have a desert climate characterized by a long, very dry, and hot summers, with an average temperature in August between 40-45°C. Temperatures in excess of 50°C are not uncommon in Kuwait and in parts of northeastern Saudi Arabia. Winters are cooler winter, with temperatures sometimes falling below 4°C. The rainy season is from October to May. The annual rainfall varies between as little as 20 mm and up to 400 mm. The predominately northeasterly winds, the shamal, can reach speeds of over 150 km/hour. Particularly in the winter, these winds often carry large amounts of dust and sand.

Figure 1. The Arabian Peninsula.

2.2 The Terrestrial Environment

The ecosystem in Kuwait and the northern parts of Saudi Arabia is typical of deserts; i.e. few and succulent, salt tolerant and often thorny bushes, scrubs and plants and relatively few species of animals. The surface layers of the desert sand forms a relatively hard crust that prevents erosion. During the late winter and early spring, especially in connection with the rainy season, colourful desert flowers and grasses cover most of the land. Desert plants are an integral part of the desert ecosystem. The plants provide shelter for small desert animals, prevent erosion, and provide food for grazing wild and domestic animals. The flora is part of the North African-Indian desert flora, dominated by different halophytes and xerophytes. The wildlife is, despite the extremely harsh conditions and extreme temperatures, surprisingly rich in species.

Small mammals such as gerbils, desert hares, foxes, rabbits, and hedgehogs are common, as well as wild ass, oryx, fennec, jackal, caracal, and several species of snakes and lizards. There are few endemic birds but the region is on the migration route of many birds that spend the summers in northern Europe.

The Arabian Peninsula is characterized by two major geological features: the Arabian Shield to the west created in the Precambrian period, and the sequence of overlaying continental and shallow-marine sedimentary rocks of the Arabian Platform to the west (Al-Sulaimi and Mukhopadhyay, 2000). The sedimentary sequence consists mainly of sand- and limestone. The eastern lowland is very flat and featureless, except for some shallow depression and small conical sandy hills with an average height of only about 40 meters. In addition to sand sheets, the area includes scattered and large connected rocky surface, which have sharp edges due to long periods of deflation (Massoud et al., 2000). Limestone, marl, and dolomites are dominant in the Tertiary layers, and it is in these formations that oil and gas can be found. The Organization of the Petroleum Exporting Countries, OPEC, estimated in 1991 that crude oil reserves in Kuwait rank third in the world at 96.5 billion barrels. This is approximately 10% of the worlds known reserves.

2.3 The Marine Environment

From a geological point of view, the Gulf is a very recent sea. Resulting from the eastward migration of the Arabian plate, the Gulf basin was probably formed during the late Pliocene era, only three or four million years ago. From an ecological point of view, the Gulf is also very recent. The last refilling of the Gulf started 18,000 years ago, but it is estimated that the current sea level was reached only five to seven thousands years ago. The Gulf is therefore one of the youngest bodies of water in the world and also one of the shallowest. The average depth is 36 meters, with a maximum depth of 90-100 meters along the Iranian coast. The volume of the water area west of the Strait of Hormuz is therefore only 7,800 km^3, which correspond to one third of the Baltic Sea's volume or 5% of the Mediterranean. The general circulation pattern of the water is counter-clockwise: currents move northwards along the Iranian coast and to the south along the Saudi Arabian coast. The surface water temperature vary between 30-35°C in the summer and may decrease to as little as 4°C in the north of the Gulf in the winter. Due to the high evaporation (about ten times greater then the input from rainfalls and rivers), salinity of the water in the northern Gulf is quite high. The water along the coast of Kuwait show salinities of around 40 ppt, and along the Saudi Arabian coast between 35-40 ppt. However, in shallow water the salinity can become much higher. A salinity as high as 70 ppt has been reported in the Gulf of Salwah and in the inner parts of the Kuwait Bay. Cold water with salinity normal for the Indian Ocean enters the Strait of Hormuz and drifts north along the Iranian coast. Evaporation increases salinity and the density of the water. This makes it gradually heavier and the water sinks. The high salinity water follow the western coast of the Gulf, and tend to pass through the Strait of Hormuz as an outgoing deeper current. The turnover time of Gulf water is estimated to be 3 to 5 years (Sheppard, 1993). Tides in the area are basically semi-diurnal, and vary from 2 to 3 meters along the Saudi Arabian and Kuwaiti coasts.

The physical factors mainly in the form of extreme temperature fluctuations and elevated salinity exert considerable natural environmental stress to the marine and coastal ecosystems of the Gulf. As a consequence, the biodiversity is significantly lower compared with the Indian Ocean. Because of the relative shallowness, the Gulf supports highly productive coastal habitats, such as the extensive intertidal mud-flats and seagrass beds. Along parts of the coast there are also areas of dwarf mangrove and coral reefs. However, the coral reefs show relatively very low biodiversity.. The shallow seabeds along the East coast of Saudi Arabia are covered with seagrass, which serves as a nursery ground for fishes, shrimps and other crustaceans. Many species of corals as well as other species of animals and several plants in the area live close to their tolerance thresholds. Characteristic for the corals in the Gulf is that the ecosystem during the winter enters a dormant stage. During these periods the reefs become more or less covered with macroalgae. As the temperature rises in the spring, the algae disappears and the corals become exposed again. In the northern Gulf, most of the subtidal areas are soft sediment bottoms. Extensive seagrass beds mostly cover these sediments, which supports a number of commercially important species such as prawns. Algae mats associated with the tidal flats are also highly productive as they during part of the year are covered with blue-green nitrogen-fixating algae. These tidal flats are a key feeding areas for wintering and migrating waders.

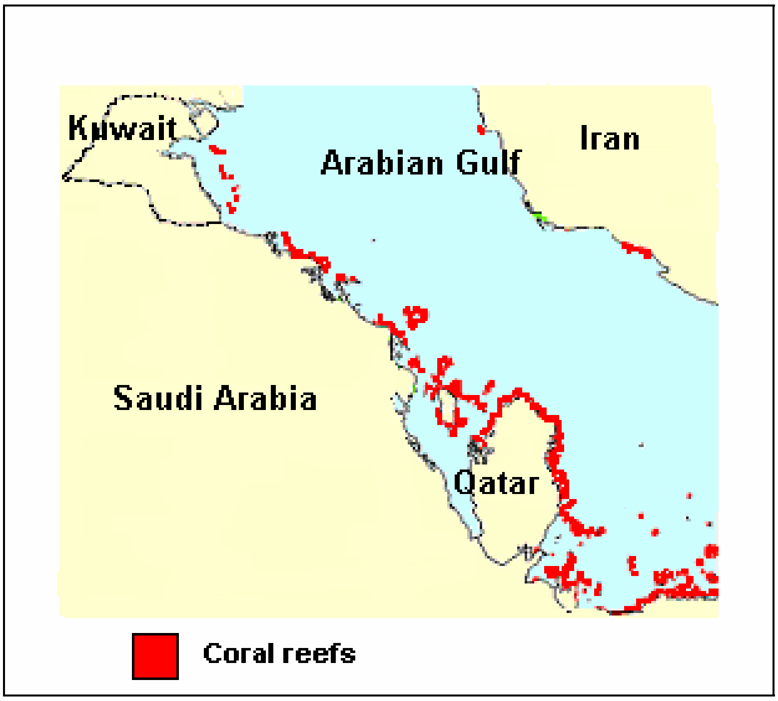

Figure 2. The coral reefs of the Gulf.

Mangrove vegetation in the Gulf is associated with soft intertidal substrates and plays an important role in the ecology of the region. Over the last half century, much of the original mangrove has been destroyed by unplanned coastal development and today; only small populations in certain lagoons and marshes are left. The northern limit for naturally occurring mangrove in the Gulf is just north of Abu Ali Island (Jubail) in Saudi Arabia. Because of severe climatic conditions in the Gulf, only one species (Avicennia marina), which is highly salt-and heat-tolerant exist in the region (Khan, 2002). Although the number of mangrove in the Gulf is low, most of the characteristic faunal zones are still present. The mangrove habitats support a variety of important species of fish, shrimps, turtles and birds. Moreover, their interactions with adjacent ecosystem make a significant contribution to coastal productivity and play a central role for the biodiversity. Like most other species groups, the fish fauna of the Gulf are less diverse than that of the adjacent Indian Ocean. However, individual species may occur in very high numbers. The fisheries of the Gulf, particularly for shrimp, are of considerable importance to the region. The industrial sector mainly uses trawlers and this sector has grown rapidly over the last few centuries. The artisanal fisheries have provided a livelihood for coastal communities since earliest history. The use of simple fishing traps set on the intertidal and subtidal zones still continue. Local fishing craft, now motorised, form the other main component of present day artisanal fishery.

Several species of whales and dolphins are found in the region. Baleen whales include Bryde’s, humpback, mink, fin, and blue whale. Toothed whales include sperm, killer, and false killer whales. With respect to dolphins and porpoises, sightings of the bottlenose dolphins and the Indian-Pacific humpback dolphin have been recorded. Dugongs are found in the inner part of the area, it is not known to exist along the shores of the Arabian Sea. The largest herd ever recorded of over 600 individuals, was observed in the Gulf of Salwah between Bahrain and the Qatar peninsula. The estimated population is 6,000-9,000 individuals, making the area most important for this species, second after Australia. All five of the pantropical species of marine turtles have been identified in the region: hawksbill, greens, leatherbacks, loggerheads and Oliver Ridley. These turtles are classified as endangered in the World Conservation Union Red Data Book. The most important part of the region for the turtles is the Arabian Sea, in terms of both the number of breeding species and the abundance of individuals (UNEP, 1999).

2.4 Human Settlements

The Arabian Gulf marine environment is important in fulfilling social, economic, developmental and strategic objectives in the region (Ahmed et al., 1998). The Gulf plays a particularly vital role in providing most of the population with fresh water from desalination plants. Fisheries are a major industry, and of great social significance. Since the discovery of oil in the 1930s, the wealth generated by the oil exports transformed the essentially primitive infrastructures of these countries in the Arabian Peninsula into those of modern states. But the discovery of oil also introduced a variety of environmental stressors in the Arabian Gulf ecosystem. The most inputs of oil to the marine environment originate from war activities, tanker accidents, and shipping traffic, but also from terrestrial sources and natural seepage. There are numerous sources of wastewater pollution in the Gulf area.

In 2002 Kuwait had a population of 2,111,561 individuals, which includes 1,159,913 non-nationals (CIA, 2002). The population is predominately Arab, but since the development of the oil industry, large numbers of foreigners have found employment in Kuwait and today about two thirds of the population are non-Kuwaitis. The influx of immigrants was due in part to Kuwait's rapid expansion as a modern state with a flourishing economic climate and massive employment opportunities. The majority of immigrants are from other Arab countries as well as Iran, India, Pakistan, Bangladesh, Sri Lanka, and the Philippines. Kuwait also has a significant population classified as bidun (Arabic for “without”), who are not citizens of any country. Many bidun claim to have lived in Kuwait for generations without receiving citizenship, while Kuwait claims they are recent immigrants who should not be granted full citizenship. Native Kuwaitis have an extremely high per capita income, pay no taxes, and have numerous social services. Kuwait City is the largest city, the capital and also the most important port of Kuwait. Other important urban areas are Mena al Ahmadi, an oil port; the port of Shuwaykh; and the new city of Ahmadi, built by the Kuwait Oil Company. The main part of the population lives within a 500-square kilometer area bounded by Jahra, the Arabian Gulf, Ahmadi and Fahaeel. Iraq had in 2002 an estimated population of 24,001,816 (CIA, 2002). At least 95% of the population adheres to some form of Islam., which includes 60-65% Shia’s and 32-37% Sunni.

3. Background to the War

The area now known as Kuwait has been inhabited since at least 5,000 BC. Kuwait’s modern history began in the early 18th century, when several clans migrated from central Arabia to the northern shore of the Arabian Gulf. These settlers created a merchant principality based on fishing, pearling and trade. Eventually the Al Sabah emerged as the dominant clan, and was formally established as rulers in 1756. At that time there was three regional states in the area, State of Baghdad, State of Mosul, and State of Basra, all linked to the Ottoman Empire. Kuwait became more important at the end of the nineteenth century due to its strategic position at the top of the Gulf. In 1899, the Kuwaiti leader Mubarak Al Sabah concluded a contract with Britain where Britain agreed to protect Kuwait’s physical integrity in return for Kuwait’s agreement not to lease, cede, or give concession of any land to a foreign power without British acquiescence. The relationship with Britain was maintained until 1961 when the Protection agreement was terminated. On June 19, 1961, Kuwait became fully independent following an exchange of notes with the United Kingdom. During the twentieth century Kuwait became important because of the its abundant oil reserves. In 1913 Mubarak permitted British representatives to survey areas of Kuwait for oil, but it was not until late 1930’s that oil was discovered. Export of oil from Kuwait commenced in 1946 and the output of oil increased considerably during the 1950-70s (Al-Yahya, 1993).

Iraq became into existence in 1921 from territory occupied by Britain during World War I, but full independence was not achieved until 1932. At various times throughout its brief existence, Iraq has made claims on Kuwait. Iraq claims that the border between Kuwait and Iraq has not been agreed upon. Kuwait's northern border with Iraq dates from an agreement made with Turkey in 1913 and was informally confirmed by Iraq in 1932. However, in 1961, following Kuwait’s independence, Iraq reasserted its claim to the emirate under the pretense that Kuwait has been part of the Ottoman Empire and its Basra Province and that Iraq “inherited” the right to rule Kuwait from the Ottomans. As a response Britain sent troops to Kuwait. In 1963, Iraq reaffirmed its acceptance of Kuwaiti sovereignty and the boundary it agreed to in 1913 and 1932, in the "Agreed Minutes between the State of Kuwait and the Republic of Iraq Regarding the Restoration of Friendly Relations, Recognition, and Related Matters." The boundary issue again arose when the Baath (Arab Socialist Resurrection) Party came to power in Iraq after a 1963 revolution. The new government officially recognized the independence of Kuwait and the boundaries Iraq had accepted in 1932. Iraq nevertheless reinstated its claims to islands of Bubiyan and Warbah in 1973, massing troops at the border. This action prompted broad Arab condemnation, leading to Iraq's subsequent withdrawal.

3.1 Oil – a Source of Conflict

Many factors contribute to the political instability of the Gulf area. Not of all of these factors are connected to the presence of large quantities of oil in the area (Klare, 2001). Even before 1908, when the first significant reservoir of oil was found in Iran, political ambition, religious differences, and greed regularly provoked conflict. The historical context of Iraq-Kuwait conflict lies in the fact that Kuwait was once a district of Iraq during Ottoman rule, before the British carved it off to form an independent state. Many of the important energy reserves span the boarder between two or more states. Because possession of these areas can lead to billions of dollars in annual oil and gas revenue, the various interested parties may choose to seize the territory through force rather than allow a rival to obtain all or part of these royalties. The presence of large reserves of oil in the Gulf has also increased the likelihood of interstate conflict by giving the nations in the region the means to produce vast quantities of modern weapons. The increased oil income has also increased the risk of internal conflict, especially in countries where the petroleum revenue has gone to a small prominent elite. The possession of these vast amounts of advanced weaponry triggered some of the Gulf leaders to expand their territory. Many analysts believe for example that Saddam Husseins' invasion of Kuwait was triggered in part by a belief that his forces were so well armed that no outside power would contest Iraq's annexation of the state (Klare, 2001).

Until recently, international conflicts were often governed by political and ideological considerations. But the wars of the future will largely be fought over the possession and control of vital economic goods, especially resources needed for the functioning of modern industrial societies (Klare, 2001). One of the more likely resources to provoke conflict between states is oil. Petroleum plays an important role in the global economy and no highly industrialized society can survive at present without substantial supplies of oil. Oil has, of course, been a recurring source of conflict in the past. Many of the key battles of World War II, for example, were triggered by the Axis Powers attempts to gain control over petroleum supplies located in areas controlled by their enemies. The pursuit of greater oil revenues also prompted Iraq's 1990 invasion of Kuwait. Of all the worlds major oil-producing areas, the Persian Gulf region is the one most likely to experience conflict in the next century (Klare, 2001).

Table 1: Oil reserves and production in the Persian Gulf area, 2001 (BP, 2002).

	Proven reserves at end 2001 Billion barrels	Percent of world reserves	Production 2001 Million barrels per day	Percent of world production
Iran	90	5.1	3.7	8.5
Iraq	113	3.3	2.4	10.7
Kuwait	97	2.9	2.1	9.2
Oman	5.5	1.3	0.96	0.5
Qatar	15	1.0	0.78	1.4
Saudi Arabia	260	11.8	8.8	24.9
Syria	2.5	0.8	0.55	0.2
United Arab Emirate	98	3.2	2.4	9.3
Yemen	4.0	0.6	0.46	0.4
Total	685	30.0	22	65.3

Possessing almost two thirds of global petroleum supplies (see Table 1), the Gulf is certain to remain the focus of intense worldwide competition as energy demand increases in the decades ahead. The Gulf's oil deposits are also highly concentrated and located close to the surface, meaning that they are among the easiest to find and relatively inexpensive to develop. As the century proceeds, the oil importing states will become ever more dependent on energy supplies from the Gulf. Oil and gas deposits located in the area will become increasingly valuable, and so the claimants to these reserves will face greater temptation to seize and occupy them through the use of force. Similarly, leaders in the region can be tempted to expand their holdings by annexing neighboring countries. Furthermore, the region is split by a multitude of power rivalries, religious schisms, and territorial disputes. The petroleum revenue creates a new ruling elite and the less fortunate can be provoked to revolt. These divisions have often triggered violence in the past and are likely to do so in the future.

3.2 The Iran-Iraq War

The war between Iran and Iraq began on September 22, 1980, when Iraqi troops launched a full-scale invasion of Iran. The Iraqi leadership believed that victory would be easy; they assumed that Iran's military strength had been greatly weakened by the revolution that had brought the Islamic Republic to power in Iran the previous year. However, they were mistaken. Although Iraqi forces won early successes, Iran rallied, held the invaders, formed new armies, and took the offensive. Iraq claimed as the reason for its attack on Iran a territorial dispute over Shatt al Arab, a waterway that empties into the Persian Gulf and forms the boundary between Iran and Iraq. The area is also known for its oil field. In 1975, a militarily weaker Iraq had signed over to Iran partial control of the waterway in the so-called Algiers Agreement. After the revolution and resultant weakening of Iran's military, Iraq seized the opportunity to reclaim Shatt al

Arab. The Iraqi offensive was initially successful, capturing the port city of Khorramshahr by the end of 1980. The Iraqi offensive caused a lot of material damage on the Iranian infrastructure. Repeated attacks on oil facilities such as Iraq's numerous assault on the Abadan refinery and the Kharg Island oil terminal in Iran caused a lot of damage. These were countered by Iranian attacks, particularly on Mina al-Bakr, Khor al-Amaya and Iraqi oil-storage tanks at the port of Fao. Apart from the immediate and highly significant economic damage caused to both sides, as oil revenues provided the primary source of military funding, these attacks worsened the already high levels of oil pollution in the Gulf.

After half a year of war Iran succeeded in making inroads into Iraqi territory. The war reached a relative stalemate, with offensives and counter-offensives launched in the boarder region between the countries. Intermittent battles frequently caused horrendous casualties, especially among the Iranian "human waves" of massed infantry. Sporadic air and missiles attacks on cities, military installations, and other economically important facilities were common throughout the war. The Iranian counter-offensive proved to be successful enough to cause Iraq to resort to the use of chemical weapons. After several years of fighting, Iraq was able to slowly take back their lost territory. But both the Iranians and Iraqis were growing weary of war after several years of fighting and to avoid an internationalization of the conflict, the United Nations Security Council proposed a cease-fire resolution. But the war continued and with terrible consequences for the environment. The marshes around Shatt al-Arab came under attack when Iranian forces dug a series of drainage channels. The intention was to drain the swampy land so that the Iranian army could use their artillery and armor. Shelling and air attacks against population centers were particularly severe at the beginning of 1987. However, some of the worst incidents of civilian targeting occurred in Iraqi Kurdistan. The Iraqi air force bombed towns and villages with a lethal mixture of chemical weapons, including mustard gas and the nerve gas sarin and tabun (McKinnon and Vine, 1991).

An Iraqi air-and-sea attack on the Nowrus oilfield in 1983 sank five Iranian ships and destroyed three oil wells (McKinnon and Vine, 1991). The oil wells gushed oil for three years causing an oil spill of approximately 300,000 to 400,000 tons of oil. By 1987, the war expanded to involve attacks on oil tankers traveling in the Persian Gulf, causing innumerable oil spills. The two belligerents also attacked several neutral ships traveling in the Gulf, and soon the Arab and Western nations became involved in the conflict. Finally, in July 1988, Iran and Iraq was forced to accept the United Nations' resolution on cease-fire and military retreat, leading to a cease-fire on the 20 August 1988. Casualty figures are highly uncertain, though estimates suggest more than one and a half million war and war-related casualties. Perhaps as many as a million people died, many more were wounded, and millions were made refugees. The final cost of the war, according to the Stockholm International Peace Research Institute, was US$ 200 billion. This equated approximately to half of the total oil revenues earned by both countries up to that time (McKinnon and Vine, 1991).

3.3 The Iran-Iraq War Aftermath

After the Iran-Iraq war ended in 1988, Iraq emerged as the leading Arab power with Saddam Hussein as a dominant Arab leader. Just after the war, the crisis between Iraq and Kuwait began to develop. The invasion of Kuwait by Iraq, on 2 August 1990, was partially linked to the historic claim by Iraq long before the era of oil exploration in the region (Husain, 1995). It was also due to the strategic location of Kuwait on the Persian Gulf, which through invasion and annexation might have provided the Iraq regime with a politically radical power base in the region by controlling the Gulf. Another factor that forced the Iraqis to invade and annex Kuwait was related to oil politics and unstable oil prices. The over-production of oil caused a slackness in world oil prices and Iraq was eager to earn more foreign exchange through stable oil prices to ease its huge debt burden from the Iran-Iraq war. Iraq's economy was ruined due to the war with Iran, and Iraq wished Kuwait to write off debts totaling $21 billion. During the early part of 1990, Iraq and Kuwait had several brotherly meetings to sort out the differences relating to the Kuwaiti loans to Iraq, boarder demarcation and the share of oil in the Rumaila oil field. Iraq had been claiming that Kuwait was "stealing" its oil income by exploiting the Rumaila oil fields, which are on the Kuwait-Iraq boarder. Saddam Hussein decided to occupy Kuwait, and in so doing, gain access to most of the oil in the region as well as get control over Shatt al-Arab and the important port of Umm Qasr. Another possible cause of the war was that the Iraqi army, numbering millions after the cessation of Iraq-Iran war was getting restless. There was always the chance that his own idle army would overthrow Saddam Hussein, but a war with Kuwait would keep them occupied (Al-Yahya, 1993).

4. Invasion, Occupation and War

4.1 Iraq's Invasion

Iraqi forces invaded Kuwait early in the morning of August 2, 1990. The invasion came as a total surprise for the international community. About 30,000-armed troops, mainly infantry, with 700 tanks followed by 100,000 advanced guards occupied Kuwait within a few hours. Kuwait's small army of 20,000 men could show little resistance and rapidly collapsed. By dawn Iraqi troops had entered Kuwait City and taken over key points such as the Royal Palace, military and police hear quarters, ministries, radio and television, hospitals, the port authority. By the 4 August 1990, Kuwait was cut off from the outside world as the Iraqis destroyed the Umm Al Aish earth satellite station. The Kuwaiti Air Force, hundreds of thousands of civilians, and the Kuwaiti ruling family were able to flee to Saudi Arabia and other neighboring countries. In 1990, the Kuwaiti population consisted of approximately 2 million people, Kuwaitis and non-Kuwaitis (Al-Hammadi et al., 1994). Having no experience with war, the population was caught unprepared by the rapid invasion. A large number of the Kuwaiti population was abroad at the time of the invasion, due to the holiday season. Less than 300,000 Kuwaitis (less than 50% of the pre-invasion population) were left in Kuwait during the occupation. More than one million expatriates, mostly from India, Pakistan, Philippines and Sri Lanka, left the country during the months after the occupation. They had to undergo considerable distress as they were transported via Iran and Jordan. Most of the 400,000 Palestinians stayed in Kuwait after the invasion.

The international community responded quickly against Iraq's aggression. Within hours of the invasion, Iraq's worldwide assets were frozen. Both the UN Security

Council and the Arab League condemned the invasion and demanded an immediate withdrawal from Kuwait. The UN Security Council passed resolution 660 directing Iraq to make an immediate and unconditional withdrawal from Kuwait. The UN also imposed wide-ranging import and export sanctions against Iraq. A few days later, Saudi Arabia and Turkey shut down the flow of oil through pipelines across their territories. On 6 August 1990, Saudi Arabia accepted a US offer of 50,000 troops to help defend Saudi territory. The operation was known as Operation Desert Shield. On the 10 August 1990, the Arab League, through majority vote, agreed to a proposal to join multinational forces to confront Iraq. Iraq claimed immediately after the invasion that their main purpose was to establish an Iraqi-controlled government (The Provisional Free Kuwaiti Government) headed by Saddam Hussein's son-in-law, and after that to gradually withdraw troops. But the response of the international community was so swift and far more condemning than the Iraqi regime had thought it would be, which frustrated and infuriated Saddam Hussein. The annexation of Kuwait and declaring Kuwait as its nineteenth province, ordering the closure of foreign embassies in Kuwait, and taking Westerns as hostages were some of the actions taken by the Iraqi regime as a result of the international response.

Table 2: Course of events

Date	Event
August 2, 1990	Iraq invades Kuwait.
August 5, 1990	UN imposes import and export sanctions against Iraq.
August 6, 1990	Operation Desert Shield
August 8, 1990	Iraq annexes Kuwait.
November 29, 1990	UN Security Council adopts resolution 678, permitting member states to use all necessary means to secure Iraqi withdrawal.
December 1990	Iraq experiments with effectiveness of explosives on oil wells.
January 16, 1991	Allied forces start bombing Iraq's position in Kuwait and Iraq. Iraq starts to burn oil wells.
January 19-23, 1991	Iraq releases oil from Sea Island terminal into the Gulf.
February 19, 1991	Majority of oil well fires started
February 24, 1991	Allied ground offensive, also known as Operation Desert Storm, begins.
February 28, 1991	Kuwait City liberated, ground war ends.
March 11, 1991	UN declares cease-fire.
March 16, 1991	International fire-fighting teams begin to extinguish oil fires.
November 6, 1991	The last oil well is capped

The Iraqi troops, at least 300,000 personnel including several armor troops, were stationed in Kuwait and along the boarder with Saudi Arabia. At the end of 1990, 700,000 allied troops were primarily stationed in the central and northeastern parts of Saudi Arabia. Both the Allied and the Iraqi troops constructed a vast amount of roads and fortifications, such as bunkers, trenches, ammunition storage shelters, and weapon pits. Approximately 3,500 military vehicles were operating throughout Kuwait during the occupation (Omar et al., 2000). The Iraqis also constructed a series of long trenches along the southern boarders, which were filled with oil and were to have been set on fire to deter liberation. Troop movements and the construction of fortifications and roads directly affected almost the entire surface area of Kuwait and one quarter of Saudi Arabian.

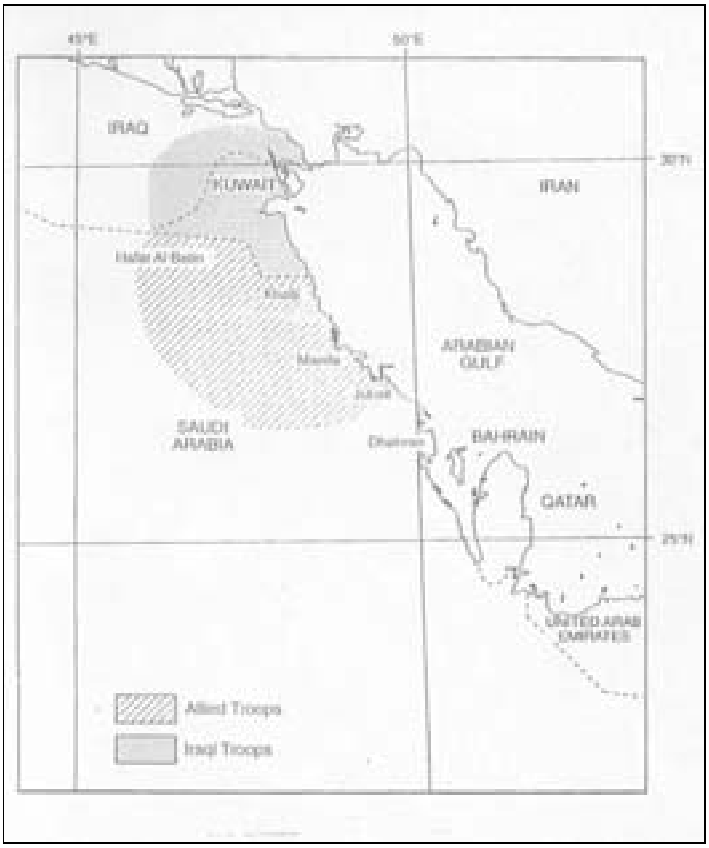

Figure 3. Map showing the areas primarily affected by the movements of troops.

After the eight years long Iraq-Iran war, the Iraqi army was generally considered to be experienced and well exercised. They had managed to stand up to the Iranian army, in spite of being at a numerically disadvantage, even though it was with the help of chemical (and most certainly also biological) weapons. Nevertheless, the development of the events during the first months of 1991 showed the reverse - that the Iraqi forces were poorly prepared for war, untrained and unmotivated in the defense of the annexation of Kuwait.

Table 3: Summary of war impacts

Type of effect	Extent of damage
Damaged oil wells	About 800
Oil seepage onto land	60 million barrels ∗
Oil released to sea	10.8 million barrels ♦
Oil in lakes	24 million barrels ∗
Number of oil lakes	246 ∗
Total land area contaminated by oil	953 km^2 ∗
Quantity of oil released into the Gulf	5.4 million barrels♦
Oil on beaches	2.7 million barrels♦
Aerial pollutants	0.32-0.95 million m^3 per day ∗
Amount of oil in trenches	498,447 m^3 ∗
Total number of bunkers, trenches, and weapon pits	375,000 ∗
Number of military vehicles operating during the war	3,5000 tanks and 2,500 armored personnel carriers ∗
Number of landmines (up to 1997)	1,646,355 ∗
Buildings set on fire	

∗ Omar, 1998

♦ Tawfiq and Olsen, 1993

4.2 Occupation

The Iraqi occupation of Kuwait caused extensive damage through destruction, plunder and pillage. A great part of the infrastructure was looted and destroyed: hospitals and health services, power plants and transmission lines, desalination plants, communication centers including telephone- radio- and TV stations, schools, universities and research institutions, hotels, banks, workshops, industries, grocery stores, the international airport and the harbor. Moreover, thousands of private residences were plundered and/or set on fire. A lot of public buildings and other commercial places were intentionally or unintentionally set on fire during the occupation (see Table 4). The Kuwait Institute for Scientific Research was completely looted and emptied of its renowned research equipment and library. The Kuwait National Museum was denuded of its jewellery, pottery, books and paintings. The occupation troops seemed to be particularly focused on the destruction of oil facilities. As much as 80% of the infrastructure in Kuwait related to oil-production were destroyed by Iraq.

Table 4: Number of private residence, industries and public buildings, set on fire during the occupation (Al-Hammadi and Al-Abdalrazaq, 1995)

	Private residence	Public & commercial building	Other buildings
August 1990	74	23	4
September 1990	154	37	8
October 1990	100	28	6
November 1990	73	21	1
December 1990	54	25	1
January 1991	63	25	1
February 1991	22	14	2
Total	540	173	23

The Iraqi regime made several efforts to destroy the identity of Kuwait (Al-Yahya, 1993). From the first day of the invasion the occupation force issued a series of resolutions aimed at eradicating the very name of Kuwait itself. Saddam Hussein stated that Kuwait was part of Iraq and had no separate identity as a nation. Hence all foreign embassies in Kuwait were ordered to be closed within four days from 20 August 1990. Names of residential suburbs, streets, schools and hospitals were changed, for example the Sabah Hospital became Saddam Hospital.

4.3 War

During the following months, the United Nations Security Council passed a series of resolutions condemning the Iraqi occupation of Kuwait. On November 8, 1990 President Bush announced a military buildup to provide an offensive option, "Operation Desert Storm," - to force Iraq out of Kuwait. In November 1990, the UN Security Council adopted resolution 678 permitting member states to use all necessary means, authorizing military action against the Iraqi forces occupying Kuwait, and demanded a complete withdrawal by the 15th of January 1991. When Saddam Hussein failed to comply with this demand, Operation Desert Storm started. The air war of Operation Desert Storm began on 16 January 1991. Thousands of sorties were flown to bomb strategic locations in Iraq and Kuwait. Iraq’s response to the air raids was moderate. Iraqi anti-aircraft fire claimed a few Allied bombers, but the most significant act was the launching of Scud missiles at Israel and Saudi Arabia. As the air war intensified, so did the Iraqi terror tactics within Kuwait. Iraqi soldiers built fire lines or barricades of trenches, minefields and oil-trenches. They also mined the oilfields and oil installations, refineries, power stations and desalination plants. Immediately after the liberation, the Ministry of Defense of Kuwait estimated that the Iraqi troops had deployed approximately 1 million of landmines during the occupation. After a while, the number of mines were changed to about 2.4 million.

By the middle of February preparations for the ground war were complete, as all peace efforts had failed. On 22 February 1991, President Bush gave an ultimatum to Iraq, saying that they had until noon on Saturday 23 February to withdraw. Iraq immediately responded by torching over 700 oil wells in Kuwait and by detonating the Mina Al Ahmadi oil terminal. The ground war started in the early hours of Sunday 24 February 1991. The US, Kuwaiti, Saudi, French and British forces advanced into Kuwait and effectively cut of any escape route for the Iraqi forces. The only road connecting Kuwait with Iraq, which passes over the Al Mutlaa Ridge became the "road of death" as the Allies bombed the retreated Iraqi troops. The U.S announced a cease-fire on the 28th February 1991. UN terms for a permanent cease-fire were agreed by Iraq in April of that year, and strict conditions were imposed, demanding the disclosure and destruction of all weapon stockpiles.

4.3.1 Destruction of Oil Wells

After the invasion of Kuwait by Iraqi forces on 2 August 1990, the Iraqi threatened to destroy the Kuwaiti oil fields if they were forced out of Kuwait by the U.S and Allied forces. Explosives were placed on wellheads, oil transfers and storage facilities during the occupation. During the retreat the Iraqis tried to blow up more than 800 wells of which more than 600 burned with flames, and about 50 only gushed oil. The aggressive acts also included the destruction of oil refineries, desalination plants, and power and water stations. The damaged wells caused air pollution through combustion products associated with well fires, and to land through oil spills, rainout of un-combusted oil and deposition of combustion products, including soot, PAH and dioxins. The air was full of soot and oil droplets, which soon covered the desert surface as well as the surface of the Gulf water. Downwind plumes of dense smoke were spread by the prevailing northwesterly winds, covered the sky and turned day into night. It is estimated that more than one billion barrels of crude oil was lost, which amounts to about 1.5-2% of the oil reserve in Kuwait (Husain, 1995). The environmental catastrophe created by the burning of the oil wells is unparalleled in the history of mankind.

4.3.2 Oil spills in the Gulf

The oil spill began on 19 January when the Iraqi forces intentionally released most of the contents of five tankers into the Persian Gulf. The next day, the amount of oil increased when the content of Al Ahmadi north tank field were released through the Sea Island Tanker Terminal. The spill moved slowly southwards along the Kuwaiti and Saudi Arabian coastline. Around January 25, most of the sea surface along the Kuwaiti and Saudi Arabian coastlines was covered with what would be the worlds greatest oil spill so far. The flowing of oil from the Sea Island terminal was later stopped via precision bombing by the Allied Air forces. On January 31, Iraqi Mina Al-Bakr oil loading terminal was open and oil started to flow into the Gulf. This resulted in a second, much larger oil spill, which also later was stopped via precision bombing. Also subsequent deliberate spills from damaged oil facilities and from several battle damaged tankers continued to worsen the spillage. Moreover, atmospheric fallout from Kuwaits' damaged wells gradually introduced a considerable additional quantity of oil in the form of oil droplets and oily soot. It is still unknown what the exact amount of oil spilled during the 1991 incident was, but it has been estimated to be between 6 and 10 million barrels.

A the main body of the oil slick moved south along the Saudi Arabian coast, winds repeatedly drove it onto shore and then back into the sea, leaving most of the northern shoreline of Saudi Arabia heavily contaminated. About 700 km of Saudi Arabian shoreline had been oiled by early June 1991 (Gundlach et al., 1993). This probably represents the maximum extent of oiling during the spill as impact by floating slicks had mostly ended and natural wave action was beginning to self-clean the beaches. The beaches consist mostly of sand and gravel, wetlands, lagoons, and muddy tidal flats, sometimes covered by vegetation. In some areas pockets of dwarf mangroves exist. There are rocks in some areas and a significant proportion of the coast is artificial, i.e. it consists of sea-walls made of concrete or boulders along roads, jetties etc. Investigations in May - June 1991 showed that the oil seldom had penetrated deeper than about 10 cm into the beach material (Hayes et al., 1993, Twarfiq and Olsen, 1993). In total the surface area contaminated with oil was calculated to be about 34 km2. About 200 thousand tonnes of oil were still present on the beaches in Saudi Arabia, and over 1.4 million m3 of beach material was estimated to be oil contaminated. Other countries including Kuwait had been spared from major quantities of oil contamination. With the exception of some small areas south of Kuwait City and on Bubyan Island, the country had no major problems with oil contamination on its beaches. During the period March - May 1991, some oil ended up on the beaches of Iran, Bahrain and Qatar. In Iran the oil may have originated from the Mina Al-Bakr oil terminal. The spills in Bahrain and Qatar may have been released from damaged ships of have been caused by deliberate spills.

4.3.3 Early Scenarios

Soon after the Iraqi occupation of Kuwait, the international community started demanding that the Iraqi troops should get out of Kuwait and threatened to evict them by force if he did not comply. The Iraqi leaders warned that they would use the scorched earth tactic if they were forced out from Kuwait. The objective was to scare the world by threatening to damage Kuwaits' oil industry by igniting oil storage facilities and blow up all oil wells in the Kuwaiti oil fields. The plan was to incite the general population to force their political leaders not to evict Iraq forcefully so that the world could gradually forget that Kuwait was a sovereign country.

King Hussein of Jordan, on 6 November 1990 at the Second World Climatic Conference in Geneva, delivered a speech on the possible environmental-, climate- and health consequences due to the exploding of the oil fields by the Iraqi regime. In his speech King Hussein highlighted the probable global impact (Husain, 1995). One of the Jordanian Royal Science Advisors, Dr Abdulla Toukan, warned that the smoke plume from the Kuwaiti oil field disaster would blacken the skies over the whole Gulf region, including Jordan, Syria and Iran. He also predicted that shading of sunlight and absorption of solar heat by black smoke from the burning oil wells would cause conditions similar to a nuclear winter scenario. The smoke would have impacted on the entire Northern Hemisphere within a few weeks. The soot would cause possible disruption of the monsoon in the Indian subcontinent and Southeast Asia. His statements attracted a lot of attention and were followed by new, more or less well founded, scenarios about what would happened if Iraq carried out their threats. In the beginning of January 1991, nine eminent scientists, including Dr Toukan himself, wrote a message to the UN Secretary General expressing their concerns about the global environmental catastrophe that would result if the Allied forces compelled Iraq to leave Kuwait. But despite their attempt to delay the attack, world leaders did not pay much attention to their calls. Toukan and the other scientists appeared several times in mass media, expressing their concerns about the effects of the smoke on the global environment. Another doomsday prediction came at the beginning of 1991. Dr Richard Turco, a famous climate researcher at UCLA, predicted in an article in Science that the burning oil wells in Kuwait would produce three million tons of soot per month (Turco et al., 1990). These clouds of soot would cover 100 million km^2, which would represent more than 20% of the earths' surface.

The above doomsday predictions were based on the generalized assumption that the open burning of crude oil would produce large quantities of smoke and soot particles. These particles would be transported to the stratosphere where they would absorb solar radiation and, therefore, reduce sunlight falling on the earths' surface. Some scientists, referring to the horrible consequences of the nuclear winter effect in the case of a nuclear war, termed the environmental consequences of the Kuwait oil fires as the "petroleum winter effect". However, the extent of the environmental disaster presented by these scientists prompted other scientists to initiate other studies. Sandia National Laboratories, a New Mexican-based research institute, presented a study that contradicted most of the theories about the fires and their global impacts (Sandia, 1991). They predicted however that the fires would have considerable impact at a regional and local level. Another group of researchers under the guidance of Dr Bakan, presented results from calculations that showed that the impact would be very local and would mainly have an effect on the Gulf-region (Bakan et al., 1991). The reason given was that the smoke plumes would not be able to reach so far up in the atmosphere, and that the particulate matter would fall out within three weeks. The amount of soot that would be able to reach the stratosphere, about 3%, was considered too small to have any impacts on a global scale. In general, Bakan et al. (1991) rejected the "petroleum winter effect" theory. The study by Small of the Pacific Sierra Research Corporation reached quite different results from those given by Toukan and the other scientists (Small, 1991). Small estimated that in the first 10 days, owing to fires in refineries, the smoke would reach a maximum of 3 km. At a later stage, smoke emission would come from the burning oil wells and would rise up to a maximum of 1 km. Based on these calculations, Small rejected the hypothesis of a nuclear winter scenario or monsoon failure, and other global impacts. He also estimated the CO_2 emissions to the atmosphere as 0.025% of the global contribution, which is quite negligible, and hence would not cause any global warming.

Some of the earliest predictions regarding the environmental impacts of the Kuwaiti oil fires were depressed and gloomy. However, many of the later numerical calculations showed that smoke would not be injected high enough to reach the stratosphere but would remain suspended within a 1 to 5 km altitude. The amount of carbon dioxide produced would not contribute significantly to the greenhouse effect and the environmental effects would be largely local and have an insignificant impact at the global scale was expected. From a global perspective, solar radiation and ambient temperature would not be altered enough to adversely affect monsoon intensity and distribution (Sadiq and McCain, 1993).

4.4 Pollution to the Air

The burning wells in Kuwait generated massive amounts of soot and gases that rose as a plume above the oil wells and dropped to the ground during inversions and still winds. The smoke carried toxic constituents and soot that were inhaled by humans and animals and covered vegetation and buildings. The burning wells also allowed significant amounts of oil to pass unburned through the flame zone, creating an oil rain which later fell to the ground and contributed to the formation of oil lakes. The oil lakes formed in the desert are also a source of emissions to the air, especially volatile organic compounds. Various national teams under a World Meteorological Organization program collected air quality sampling and monitoring data. Collectively, the data from these programs indicated that, with the exception of particulate matter, pollutant levels were surprisingly low. The smoke from the fires darkened the surrounding atmosphere and had a significant impact on the local climate. With the decrease in the number of wells on fire, the concentration of pollutants in the air decreased.

Figure 4. Kuwait City May 2, 1991. The smoke from the oil fires affected the city during much of the year after the war.

Table 5: Amount of oil and gas burnt, based on estimates in February 1991. (Husain, 1995)

Oil field	Wells on fire	*Burning rate* tons/day/well	Total oil burned ton/day	Amount of gas m^3/well/ton of oil	Total gas burned million m^3/day
Neutral field	25	50	1,250	100	0.124
Sabriya	75	600	50,000	100	4.3
Raudhatain	50	600	30,000	100	2.9
Umm Gudair	50	600	30,000	100	2.9
Bahra	25	600	15,000	100	1.5
Minagish	50	600	30,000	100	2.9
Burgan	350	600	200,000	100	20.0
Total	625		~355,000		~35

4.4.1 Smoke Plume

The plume height and its horizontal spread and migration were a function of the extent of damage to the wellheads, the pressure inside the well, and the wind speed and direction. About 25% of the plumes from individual fires emitted white or light gray smoke, while others emitted black or a mixture of black and white smoke (Ferek et al., 1992). Fires producing white smoke were highly enriched with crystalline salt particles of sodium and calcium and the black smoke was due to a high content of elementary carbon. The smoke plume was usually within a 1-3 km altitude and was never detected above 6 km height from the fires (Husain, 1998). Because of the prevailing north-westerly wind near the source of burning, most of the time the plume was moving towards the eastern part of Saudi Arabia over the Persian Gulf coastline. The World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP) found out that the metrological and geographical conditions in the area during the time of the fires were such that materials in the plumes were largely limited to the horizontal cloud without mixing with higher or lower layer of air. As a result, the pollution levels at population centers in the region were much lower than initially predicted.

Figure 5. The burning oil wells generated heavy smoke which affected much of the northern and central parts of the Arabian Peninsula.

4.4.2 Gases to the Air

The burning oil wells produced large amounts of gases such as sulfur dioxide, hydrogen sulfide, nitrogen oxides, carbon dioxide, ozone and, depending on the rate and efficiency of combustion, small amounts of carbon monoxide and other oxides.

Table 6: Total emissions from the smoke plume (Sadiq and McCain, 1993).

Parameter	Estimate (million metric tonnes)
Carbon dioxide (CO_2)	133
Carbon monoxide (CO)	0.8
Elemental carbon	8
Sulfur dioxide (SO_2)	2.3
Nitrogen oxides (NO_x)	0.08
Methane (CH_4)	0.3

The early predictions about an increased global warming due to the massive emissions of carbon dioxide from the burning oil fields, turned out to be wrong. The total addition of carbon dioxide to the atmosphere from the burning oil wells was 1-2 million tons per day, and in total 133 million metric tons (Sadiq and McCain, 1993). The total emission of carbon dioxide from the fires during 1991 was only 1.5% of worldwide annual emissions from fossil fuels and biomass burning and had therefore only a slight impact on global warming, even on a short-term basis (Husain, 1998). The contribution of sulfur dioxide to the atmosphere as a result of the fires was 5,500-65,000 tons per day, which is about 57% of that emitted from electric utilities in the United States (Green Cross International, 1998; Husain, 1998). No global impact was seen of the sulfur dioxide, but the emissions could have contributed to acidification on a more local scale.

The smoke from the fires was analyzed by a number of researchers during the period March to November 1991. The efficiency of the burning oil fires was found to be much higher than predicted. In most cases, 95-98% of the carbon was in the form of carbon dioxide in the plumes (Hobbs and Radke, 1992). The concentration of oxides of methane, nitrogen, and hydrogen sulfide in the smoke was negligible, and the transformation and oxidation of sulfur dioxide to sulfate was very rapid, almost 50 to 60% of the transformations took place within one hour of burning (Husain, 1995). Compared to the previous years level, the monthly concentrations of sulfide dioxide, hydrogen sulfide, nitrogen dioxide and ozone had increased significantly during the period of March to November 1991 at locations in the Eastern Province of Saudi Arabia, but they were still within permissible limits. In addition to the conventional pollutants released, there is evidence that PAHs were formed during the combustion process and were absorbed to particulate matter (Green Cross International, 1998).

4.4.3 Soot and Particles

The burning oil well also produced soot and particulate matter, containing partially burned hydrocarbons, which are potentially hazardous to human health and vegetation growth. In addition to hydrocarbon combustion products, the smoke contained other components, including various heavy metals. Such metals include nickel, small amounts of vanadium and iron, and trace quantities of aluminum, beryllium, cadmium, calcium, chromium, arsenic, silicon, zinc, and lead. The release of metals and other elements are discussed further in Section 4.5.4. It has been estimated that 5,000 tons of soot and particulate matter were released into the air every day during the fires (Green Cross International, 1998). On average, 2% of the fuel burnt in the oil fields was emitted in the form of particulate matter, out of which 20-25% was soot (Ferek et al., 1992). This estimation is much lower than many of the early calculations of the amount of soot from the fires.

However, the emission of soot particles from the fires was found to be 10% of the smoke released globally by fossil fuels and biomass burning and had an obvious regional impact (Husain, 1998). According to measurements, 75-80% of the sun's radiation was absorbed by the smoke plumes from the fires (Hobbs and Radke, 1992). Increases in particulate and smoke density in the air resulted in a significant decrease in temperature (Husain, 1995). The average temperature in Kuwait and northern Saudi Arabia dropped by about 10°C between February and October 1991. About 250 km south and southwest of the fires the temperature dropped 5-8°C. With a distance of 750 km and more a temperature decrease of 1-2°C was observed.

Figure 6. The soot particles accumulated at an altitude of approximately 1000 meters where they formed a distinct layer which was clearly visible during takeoff and landings.

Figure 7. Soot particles from the oil fires accumulated on the surface of the Gulf. Picture taken from the beach in southern Kuwait near the Saudi border.

The high concentration of particulate matter found in the air in Saudi Arabia and Kuwait, often exceeded permissible levels, especially on windy days and when the wind blew northerly or from the northwest (Husain, 1995). As the number of wells on fire decreased, the particulate concentration was also reduced, which may partly be a result of the decrease in the source strength as well as a change in the climatic conditions. The particles were manly hydrophilic and were rather quickly washed out of the atmosphere by rain and mist. For this reason, the soot plumes had no impact on the climate further away from the Persian Gulf.

Oil and natural gas contain trace quantities of the naturally occurring radionuclides uranium (238), radium (226), and thorium (232). The burning oil wells caused an unknown but rather small emission of uranium to be uniformly deposited on Kuwait soil (Bou-Rabee et al., 1995). But the use of uranium-tipped antitank shells during the war caused a much bigger uranium contamination of the environment of Kuwait.

4.4.4 Air Pollution from Military Operations

The major Allied troop deployment was in Saudi Arabia, especially in the Eastern Province and Riyadh region. Troop deployment started in August 1990 and continued through January 1991. Troop deployment affected air quality by enhancing soil erosion and thereby increasing the airborne particulate in the area, plus emitting pollutants from military vessels. The ground operation, including preparatory exercises, etc., was estimated to have consumed about 7 billion gallons of fuel and air operations used more than 600 million gallons of jet fuel during the crisis (Sadiq and McCain, 1993). The major pollutants emitted as emission products during ground and air operations are shown in Table 7. The majority of these pollutants were emitted within a short period of about 2-3 weeks during February 1991. This suggests that concentrations of some of these pollutants might have been enhanced several times greater than background levels during this period.

Table 7: Total emissions from fuel consumption during the Gulf War (Sadiq and McCain, 1993).

Parameter	Estimate (tons)
Carbon dioxide	65 million
Total particulate matter	6370
Elemental carbon	4500
Carbon monoxide	38597
Nitrogen oxides	98036
Sulfur dioxide as sulfuric acid	254
Toluene	39
Anthracene	36
Flourathene	8
Pyrene	10

Considering the short period of war (only 43 days), the small area to which it was confined, and the quantities of ammunition used, it is suspected that during the peak war period, the population in the area, along with the military personnel, would have been exposed to many unknown chemicals.

4.4.5 The Rain of Oil

The oil well fires allowed significant amounts of oil to pass unburned through the flame. Some wells did not ignite when detonated by the Iraqi troops and a significant number of wells were gushing oil to various heights depending upon reservoir pressure. The uplifted particulate matter and the gushed oil created an oil rain, and were later deposited on the surface, contributing to the formation of oil lakes (see Section 4.5.3). Fine droplets traveled with the smoke plume for some distance and then fell to the ground together with soot fallout, covering large areas of the desert with a black tar-like coating (Hobbs and Radke, 1992).

4.5 Impacts on the Terrestrial Environment

It is clear that the greatest damage caused by the oil pollution was on land. The destroyed oil wells spread large volumes of oil to the desert, forming hundreds of oil lakes. Fallouts of oil droplets from unburned oil formed a mist of oil and smoke that at times was observed throughout the entire Kuwait and large parts of Saudi Arabia, Iraq, Bahrain and the Emirates (Sadiq and McCain, 1993). In an assessment made seven years after the war the state of the environment had improved substantially (Green Cross International, 1998). Sand and vegetation concealed the areas that have been covered by soot. Many of the oil lakes have been removed or have been covered by sand and dust. In 1998 the desert was relatively green because of higher than usual rainfall and the resulting growing of annual grasses. But even though the surface seems to have recovered, the oil trapped in the surface layers of sand is slowly percolating the soil and threatening the groundwater aquifers (Omar et al., 2000).

4.5.1 The Distribution and Fate of the Oil

The proven oil reserves of Kuwait are estimated at close to 100 billion barrels. The Neutral Zone area, which Kuwait shares with Saudi Arabia, holds an estimated 5 billion barrels of reserves, half of which is claimed by Kuwait. Most of Kuwait's oil reserves are located in the 70-billion barrel Greater Burgan area, which is comprised of the Burgan, Magwa and Ahmadi structures. Greater Burgan is widely considered the world's second largest oil field, surpassed only by Saudi Arabia's Ghawar field, and has been producing oil since 1938. Kuwait's Rawdhatain, Sabriya, and Minagish fields have large proven reserves as well, with 6 billion, 3.8 billion, and 2 billion barrels of oil, respectively. All of these fields have been producing since the 1950s.

Figure 8. A burning oil well surrounded by oil which also is on fire.

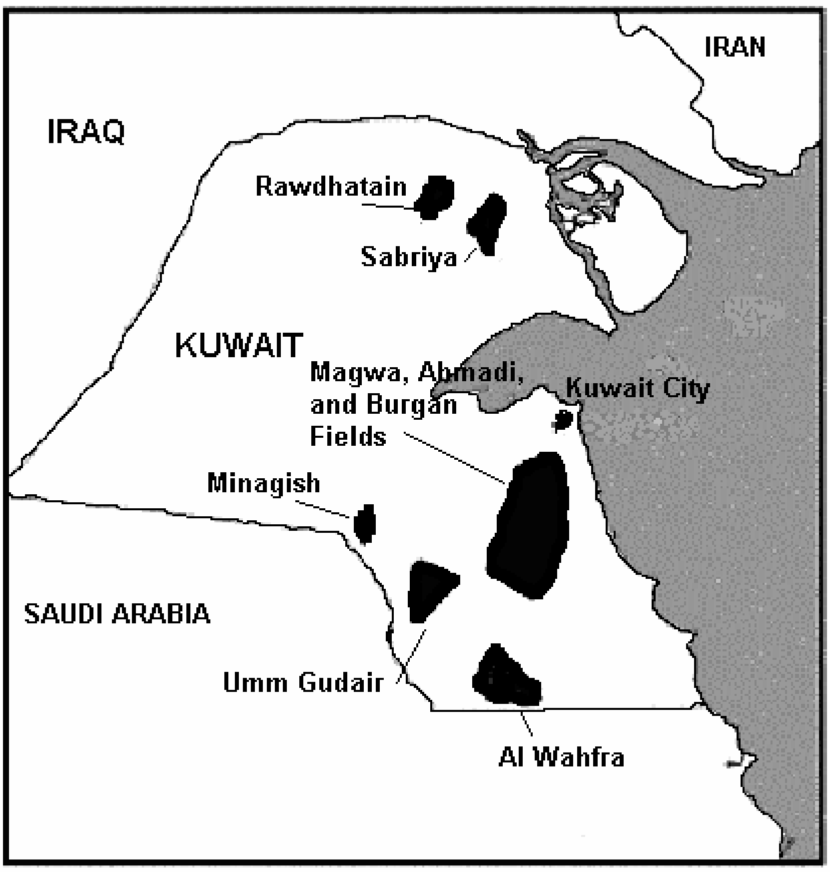

Figure 9. Major oil fields in Kuwait (EIA, 2002).

The Iraqi occupation forces placed explosives in Kuwaiti oil wells shortly after the invasion in August 1990. The purpose was to blow them up in the case of a counteroffensive. In December 1990, as the war seemed to get closer, the Iraqis tested to blow up six oil wells to analyze the capacity of the explosions. During the air raids by allied forces in January 1991, it is believed that 60 wells were blown up by Iraqi troops, while 34 wells packed with explosives, were blown up unintentionally due to the heavy bombings by the Allied forces (Husain, 1995). Just before the conclusion of the war, the Iraqis ignited more than 800 wells detonated with explosions out of which 782 exploded. More than 600 of the exploded wells burned with flames, and around 80 only gushed oil (see Table 8).

Table 8: Kuwait oil well damage by field (World Oil, 1991; Al-Besharah, 1991; EPC, 1991; Kwarteng and Bader, 1991, quoted in: Sadiq and McCain, 1993)

Oilfield	Wells before invasion	Wells on fire	Wells gushing	Wells damaged
Burgan	433		24	28
Magwa	148	350	6	21
Ahmadi	89		3	17
Minagish	96	50	-	1
Umm Gudair	45	50	2	7
Bahrah	8	25	2	11
Sabriya	72	-	4	-
Raudhatain	84	50	2	9
Ratga	144	-	-	5
Wafra	-	25	33	-
Romeilla	-	75	-	-
Total	1049	625	76	99

It is believed that the explosions did not work effectively enough to set these wells on fire. The oil from these wells and unburned oil the burning wells formed more than two hundred oil lakes that gradually filled up in the desert. During the next few days the growing quantities of smoke spread slowly, soon covering an area of 11,000 km^2 but remaining at it’s thickest over Kuwait’s coastal area (McKinnon and Vine, 1991) (see Section 4.4.1). The air was full of soot and oil droplets, which soon covered the desert surface as well as the surface of the Gulf water. The burning oil wells produced large amounts of gases as well as particulate matter containing hydrocarbons and heavy metals. The total amount of oil lost due the destruction of the oil wells has been debated extensively (Sadiq and McCain, 1993). It is generally agreed that a figure of about 600 000 tons per day was lost during the peak period of February to April 1991. It is estimated that more than in total about 150 million tons of crude oil was lost because of the war. This amounts to about 1.5-2% of the oil reserve in Kuwait.

Figure 10. The oil from the damaged oil wells formed lakes, sometimes several hectares in size.

Figure 11 (see Figures 11 and 12 below).

Figures 11 and 12. Exploded oil installations at the Al-Ahmadi Refinery, April 1991

Figure 13. Destroyed oil installations in the Burgan Oil Field, April 1991.

4.5.2 Fighting the Fires

Most of the burning wells were high-pressured wells and the mixture of oil and gas spurted/gushed several meters up in the air. Most of the wells in the Burgan oil field and the Minagish oil field were high-pressure wells, with uncontrolled flow of 10,000 barrels per day, in some wells as much as 90,000 barrels per day. Many of the oil experts, for example the engineers from Kuwait Petroleum Corporation (KPC), underestimated the burning capacity of the destructed oil wells. Based on the pressure in the reservoirs, KPC asserted that sustained fire would not be possible, as the well would not produce enough oil to support the fire. Neither KPC nor the fire fighting companies was ready to handle such an extraordinary event. To extinguish all of the oil fires and to get completely control over the wells took almost six months. However this proved to be much faster than the experts initially thought. During February – March, as the situation was at its worst, the experts feared that it would take years to extinguish all the burning wells. The burning oil wells represented a unique set of problem, never seen before. Such a large number of oil installations have never been set on fire simultaneously before, and never before had firefighters had to deal with the high risk because of the presence of landmines, unexploded bombs, and booby-traps. The pollution from the burning oils did also posed a serious health risk and the oil lakes made the access to the sites even more difficult. At the early stage, the extinguishing of the oil fires proceeded at a slow pace, partly because of the lack of water to fight the fires and the nearly complete destruction of the Kuwait infrastructure (Husain, 1995). In addition, in the early days, the road and the air communication between Kuwait and the rest of the world was heavily damaged, and it took weeks or months to make it operational again.

Figure 14. A damaged oil well still gushing oil and gases after the fire has been extinguished.

In the initial stage, attention was focused on controlling those wells that were gushing oil and gas but were not burning. The first fires were extinguished in early April 1991, using seawater at a rate of 4000 gallons per minute (Husain, 1995). Seawater was also used to cool down the surrounding area before extinguishing the fires. In several cases, due to the lack of water, liquid nitrogen was used to conduct a more efficient cooling. The added advantage of using nitrogen was that it provided more efficient cooling. Another method used was to drill parallel and horizontal relief wells in order to direct the flow of oil and gas through the relief wells, thus reducing the pressure of the main stream. A Hungarian team used two Mig-21 turbine engines to simply blow out the fire. Another popular technique was to explode the wellhead with dynamite. The explosion used all the oxygen near the burning source thus suffocating the fire. It is worth mentioning that sometimes sulfur dioxide gas created dangerous conditions during this work (see Section 4.8.5).

Table 9: Extinguished oil wells (Husain, 1995).

Time	Wells under control
May 1991	140
July 1991	265
August 1991	350
September 1991	500
October 1991	730

4.5.3 The Oil Lakes

The gushing and blazing oil wells spread vast amount of oil onto the land. The oil formed networks of rivers and lakes. Attempts have been made to calculate the volume and area of the oil spill. However, the areas covered with oil varied widely in shape, size, and depth, with time. The character of the oil and the conditions of release to the ground also affected the character of the oil coverage of the ground. The total volume of oil forming lakes and rivers on the ground has been estimated to between 10 and 20 million tons (Omar et al., 2000; Salam, 1996). During the acute phase February – December 1991, up to 200 km^2 of ground was covered with oil forming about 250 lakes. In 1992 the figure had decreased to about 50 km^2, partly due to weathering, penetration of oil into the ground, coverage of oil by dust and sand, and physical removal (Kwarteng, 1998; Kwarteng, 1999). As the southern Greater Burgan oil field and the northern Raudatain and Sabriya oil field sustained most of the damage, the majority of the lakes were formed in these areas. During the acute phase the oil in these lakes had a depth of up to 2 m. The oil has subsequently penetrated the ground to varying depth, depending on the nature of the underlying soil (Al-Awadi et al., 1995). During the acute phase the largest lake was situated in the Burgan oil field and measured 6x12 km. Because of the continuous evaporation of oil and oil seepage through the soil, the exact depth of some lakes will never be known.

Table 10: Areas and volumes of Kuwaiti oil lakes (Salam, 1996)

Oil Field	Area of Oil Lakes (km^2)	Volume of Oil (million m^3)
Wafra	3.26	1,956
Burgan	25.06	14,520
Minagish	0.19	95
Umm Gudair	0.27	135
Raudhatain	12.28	2,456
Sabriya	6.85	3,083
Bahra	0.68	408
Total	49.13	22,653

By 1995, the oil lakes in all the fields, with the exception of Burgan were hardly observable on satellite images (Kwarteng, 1998). The surface coverage of the oil lakes remaining in the 1995 based on digital image data was about 39 km^2. This area represented a 20% reduction in the area reported in 1992. The total area calculated in 1998 was about 24 km^2. It should be noticed though, that much of the surface area of the oil lakes were covered by sand and could not be observed by satellite image.

Figure 15. Oil lakes in the Ahmadi Oil Field, May 1991.

Under ideal conditions petroleum hydrocarbons in soil will eventually be biodegraded to carbon dioxide and water and will escape to the atmosphere. However, under conditions such as those in the Kuwaiti desert this process will take a very long time. Concentrations of oil-associated metallic pollutants, especially nickel and vanadium, will remain in the upper soil layer. Studies have been carried out on soil profiles in the greater Burgan oil field to determine the level of contamination and depth of penetration by oil (Al-Sarawi et al., 1998; Massoud et al., 2000). Very high concentrations of petroleum hydrocarbon, which decrease with increasing depth, have been found in the heavily contaminated soils. That indicates a direct input from the oil lakes. Also high levels of heavy metals like vanadium, nickel, cadmium and lead was found in the soils. This is probably caused by contaminations from the lakes and/or from the large amount of airborne fallout deposited on the ground.

The crude oil contains organic sulfur, which may contribute to the acidification of the ground. Organic sulfur gas may also be deposited with rain or dew. The crude oil flooding the oil fields contains high levels of organic sulfur. Together with the dry deposition of SO_2 gas emitted from the burnt oil could provide additional sources of sulfur to the soil. This sulfur acts as source of sulfate. The surface layer of sand and gravel is cemented together into a hard mass by oil droplets and soot, and preventing the atmospheric air from penetrating the soil surface and thus creating anaerobic conditions. In these poorly aerated soils, sulfate ions tend to be unstable as they are reduced to sulfide ions by aerobic bacteria. Sulfide ions will, in turn, form gaseous hydrogen sulfide. Moreover, oxygen deficiency would curtail the absorption by plants of both nutrient and water. In the short term the soils will maintain their alkalinity, but on the long term the continuous release of sulfur in acid form will undoubtedly turn them into acid soils.

4.5.4 Emissions from the Oil Fires

During the and after the war, the air in Kuwait was heavily polluted with the smoke from the burning oil wells. Kuwait, Bahrain, and the northeastern part of Saudi Arabia along the Arabian Gulf were covered more frequently with smoke. In addition, crude oil was emitted under high pressure and resulted in an oil mist that was observed throughout Kuwait (Sadiq and McCain, 1993). In 1992 the total area covered by oil mist was 1722 km^2, representing 10% of the total surface of Kuwait (Kwarteng, 1998). Downwind plumes of soot and particulate matter were carried mainly by the prevailing northwesterly winds, and resulting in a spreading of components in a northwest-southeast line of land stretching from the oil fields. About 50% of the soot was deposited within 100 km from the fires, but the presence of soot from oil fires was observed even beyond 500 km from the source (Husain, 1998). Most of the soot fell out in southern Kuwait and in northeast of Saudi Arabia.

In addition to hydrocarbon combustion products such as various poly aromatic hydrocarbons (PAHs), the smoke contained other components, including various heavy metals (mainly vanadium, aluminum, iron and zinc, but also trace quantities of beryllium, cadmium, calcium, chromium, arsenic, silicon, mercury, nickel, and lead). The levels of heavy metals increased in the direction of the wind from the oilfields, especially vanadium and nickel. The oil fires emitted approximately 7,200 ton vanadium, 2,000 ton nickel, 900 ton aluminum, 750 ton iron, 430 ton zinc, and nearly 150 ton each of mercury and cadmium (Sadiq and McCain, 1993).In addition the burning crude oil produced a wide range of combustion products: carbon dioxide (CO_2) and carbon monoxide (CO), sulfur dioxide (SO_2), oxides of nitrogen (NO_x), volatile organic compounds (VOCs), ozone (O_3), and acid aerosols.

The crude oil contained varying quantities of brine, which was emitted along with crude oil. In places concentrations of organic salts were so high that the color of many of the Kuwaiti oil fires changed from dense black to gray white. Sodium and chloride were the major constituents of inorganic salts emitted by the oil fires (Hobbs and Radke, 1992). The amount of salt that spread with the smoke and soot from the fires were very high, and could together with other pollutants cause significant negative impacts in the environment. Measurements show that the salt content of the soil has increased as far as 200 km away from the Kuwaiti oil field (Sadiq and McCain, 1993). High sodium concentrations adversely affect the soils, especially its structure. The mixture of soot, hydrocarbons and other organic compounds did not only settle on land, but reached also the Gulf. Especially the area along the Saudi Arabia coastline suffered from this fallout. The PAHs, which were produced during the oil fires, are different from those resulting from the natural degradation of the oil spill. The distributions of these PAHs have been assessed by some experts (Fowler et al., 1993). These investigations show no large-scale contamination of the coastal area of the Gulf.

4.5.5 The Desert Crust

In areas with a more humid climate, the ground is normally covered with vegetation, which stabilize the top layer and prevents erosion. In desert systems, vegetation is sparse and the top layer is made up of a fragile hard surface crust, stabilized by mechanical, chemical, and biological forces. Disruption of the desert surface by military activities before, during, and after the war destroyed this protected layer over large areas. Almost 300,000 Iraqi soldiers were transported to Kuwait and the main parts of them were stationed in the desert near the Saudi Arabian boarder. In addition allied forces counted around 700,000 personnel, most of them stationed in the northeastern area of Saudi Arabia (see Figure 3). Tanks, troops, and personnel carriers moved across the desert, hundred of kilometers of ditches were dug and bunkers were constructed, military debris and wastes were left on the ground, and millions of landmines deployed throughout the desert. The minefields were heavily bombed to enable secure corridors for the Allied troops. The Allied bombing of Iraqi defenses in Kuwait was also very large. A series of trenches constructed by the Iraqi soldiers along the southern Kuwaiti boarder were filled with oil and some stretches set on fire in an effort to halt the Allied troops. Together with the oil from the destructed oil wells these factors also contributed to the disturbance of the desert surface.

All these activities had a negative impact on the fragile desert ecosystem and in particular the desert crust. By upsetting the stability of this crust, erosion was accelerated and the ability of the soil to support vegetation was reduced. Also the chemical properties of the soil was changed (Massoud et al., 2000). Studies of the evolution of sand dunes in Kuwait after the Gulf War has showed a sharp increase in the formation of dunes. This has been explained by the disruption of desert surface by military activities (Al-Dabi et al., 1997). The moving sand has covered farmland, and blocked irrigation canals and roads. In addition compaction of the top layer of soil by the vehicles has reduced the infiltration capacity of the soil and may cause greater erosion and deeper channels during rainfalls (Husain, 1998).

4.5.6 Oil Trenches

During the occupation of Kuwait the Iraqi forces constructed a large number of trenches in the southern and northeast portion of Kuwait. These trenches were filled with oil through pipelines from several oil fields in Kuwait. The purpose of this was to set the oil on fire in an attempt to prevent or delay land or sea attacks by the allies. In some cases these oil trenches were ignited, but most of them remained more or less intact after the war. A total length of 120 km of trenches was dug along the southern border zone. These trenches contained an estimated 3,5 million barrels of oil (Misak et al., 2001). The total amount of oil in trenches is estimated to be about 500,000 m^3 (Omar et al., 2000). To fill the trenches, Iraqis established a complex network of pipelines, roads and tanks, causing severe damage to large areas. Due to mechanical impacts and oil contamination damage was caused both to the vegetation and different forms of wild life.

During the rehabilitation after the war, the oil from the trenches was transported to a dumping area in the Burgan oil field. Most of the trenches were then filled with soil. However, still after ten years, oil still is present as a 20-90 cm layer in the ground in the area of the trenches (Omar et al., 2000). In addition, the vegetation has not be able to grow in the area of the trenches. During the rehabilitation phase, the damaged surface area increased by at least 20% as a lot of heavily equipment was used for the restoration. In addition oil has contaminated a wide area on both sides of the trenches.

4.5.7 Vegetation

As mentioned above, there are some 400 species of plants in the desert ecosystem in Kuwait (Green Cross International, 1998). The desert soil support annual as well as perennial plants. Especially after the yearly rain, the desert flourish. The annual plants, however, are short-lived and the overall impression of the vegetation during the rest of the year is that it consists of thorny shrubby species. Over large areas the surface area of the desert was severely damaged by the war. The impacts were caused by troop movements, digging and filling trenches, landmines, oil spills, and soot and salt deposition from the fires. Of the area directly affected of troop movements, combats, and military camps, around 40,000 km^2 (Kuwait, northeast of Saudi Arabia, southern Iraqi), approximately 50% was completely destroyed (Sadiq and McCain, 1993). The oil fires, and especially the oil lakes, caused physical damage to vegetation. The entire vegetation cover around the burning oil fields disappeared either due to the oil coating or the high temperatures. The volatile organic compounds (VOCs) of the oil lakes were constantly evaporating due to the high summer temperature, causing exposure of the desert plants to VOC-pollution. The blazing oil wells also emitted oxides of sulfur and nitrogen, adversely damaging the flora. Activities such as ground troop deployment and movement, erection of defensive structures, and allied bombing of Iraqi positions also damaged the desert vegetation. Furthermore, extensive damages of the oil fields during the fire fighting operations, due to vehicles movements, digging of walls, ditches and roads also caused damage to the vegetation. Some areas were heavily salinated from the salt water used in fire fighting efforts and due to the brine mixed with the oil.

As a result of the oil fires, drops of oil, salt and particles of soot fell out on the ground and on vegetation in a large areas, especially in Kuwait and southwards into Saudi Arabia. This outfall was obvious during several months, throughout the most extensive period of the oil fires. Shrubs, trees, plants and other vegetation were covered at first with black spots, which soon formed a uniform thick layer of oil and tar (Hobbs and Radke, 1992). Gaseous pollutants generated by the oil fires and the emissions from the military vehicles and airplanes also caused impacts on the vegetation. Ground measurements showed relatively high concentrations of sulfur dioxide in Kuwait, mainly in the vicinity of the oil fire sources (Sadiq and McCain, 1993). However, in other areas, the concentration of gaseous pollutants like carbon dioxide, nitrogen dioxides, and ozone, were below the threshold causing plant injury.

An obvious, “positive” effect on the vegetation in the area was the considerably lower temperature and the less intensive sun radiation due to the smoke, during the period from January through November 1991. This made the spring of 1991 much greener than during normal years. Furthermore, during the years 1991 - 1995 the rainfall over much of the northern Arabian peninsula was higher than normal (Kwarteg, 1999). This increased rainfall increased the recovery of the vegetation. Additionally, the soot and tar stabilized the sandy soil and prevented the blowing away of plant seeds, and increased the changes to vegetation growth. In 1998 most of the soot and black oil had disappeared. However, over large areas the dark soot/tar was concealed under a thin covering of sand and/or covered by vegetation and were not visible on satellite images used in the investigation. Seven years after the war most of the desert appeared to be recovering if measured by the re-emergence of plant life (Green Cross International, 1998). However, there are many areas where no recovery at all is visible or where it is proceeding very slowly. In addition, there appears to have been a recovery primarily of salt tolerant species. No nationwide, ground-based survey has been conducted to compare plant diversity before and after the war. The presence of minefields limits the possibility to carry out such investigations.

There are several nature reserves and protected areas in Kuwait. These were established in the prewar period to protect endemic and migratory wildlife species, as well as the local ecosystem. The National Park of Kuwait, approximately 330 km^2, was seriously damaged during the war (Omar et al., 2000). The invasion of Kuwait resulted in what was considered the complete loss of the results from twenty years of effort to protect and conserve both vegetation and wildlife in Kuwait. It has taken the government almost seven years to rehabilitate the park area from the damages caused by bombing, digging of trenches, and landmines and much work still remains.

4.5.8 Wildlife

The desert ecosystem support several species of wildlife indigenous to the Arabian Peninsula, in addition to migratory birds that pass through the area. Gazelle, dromedary (“camels”), donkey, Arabian hare and other rodents, hedgehog, porcupine, wildcat, jackal, and wolf are examples of some of the more conspicuous mammals. In addition several species of lizards and snakes are found. Different animal populations in the Gulf region were affected by the war in different ways. We can assume that the smoke from the oil fires affected all wildlife affecting the respiratory, blood and immune systems. In addition, it is likely that mines, bombs and ammunition killed and injured wildlife such as camels as well livestock, and horses. The movement of tanks, trucks, and the many and extensive trenches particularly in the southern parts of Kuwait and Iraq, tore up the desert and destroyed fragile wildlife habitats. Oil lakes mistaken for water bodies attracted birds as well as insects. The migrant as well as local birds were badly affected by the burning oil well fires. At night large numbers of birds were flying into the fires and died. Some of the birds managed to get trough the hot gases, which resulted in burns and oil contamination. Birds were found covered with thick oil as they landed on the oil-flooded surface, near the fires (El-Baz, 1992). The large concentration of personnel in the desert, constituted itself as a disturbing element. Trigger-happy soldiers shot directly at animals, and animals were frightened by the noise, not the least from low-flying aircrafts. The intense traffic, especially in northern Saudi Arabia, killed and injured many animals, in particularly dromedaries.

Not all the impacts of the war were however negative. The extensive areas of landmines in Kuwait and the southern parts of Iraq could serve as a place of refuge for smaller animals. Rodents, for example “desert-rats” and hares, as well as hedgehogs, “desert-cats”, lizards, and snakes were protected after the combats, as the minefields provided protection from humans. This is an example of the positive impacts on the ecosystems of wars and war-like conditions that was discussed initially. Similar phenomena have been observed in other parts of the world. An example is the demilitarized zone of the Korean Peninsula, which is a no-man’s land stretching across the entire peninsula. The area provides a sanctuary for a wide diversity of Korea’s species, many now rare or extinct elsewhere. Also the boundary-line between the former East and West Germany acted as a protected area in the middle of a region, which otherwise suffer from extensive human impact.

4.5.9 Agriculture

The agriculture in Kuwait and Saudi Arabia is only a small portion of the GDP (Gross Domestic Product). Approximately 1% of the Kuwait’s area is used for agricultural purposes, mostly along the coastline. Some farms using desalinated groundwater are located in the northeastern part of Saudi Arabia. These farms are cultivating wheat, dates and vegetables. Iraq has a more extensive agriculture producing wheat, rice, and cotton. Most of the agriculture in Kuwait was destroyed during the war. The Iraqi occupation forces destroyed systematically greenhouses and irrigation systems. Many of the water pumps, generators, agricultural equipment, tools, and other items were stolen. The agriculture in Saudi Arabia is to a large extent dependent on foreign guest workers, and most of them left the country during the autumn of 1990, causing a 50% decrease in agricultural production in the Eastern province of Saudi Arabia. The damages on the agriculture in Iraq were manly caused by the UN-embargo, which stopped the import of fertilizers and pesticides.

The war affected the agriculture in northeastern Saudi Arabia and in Kuwait in a variety of ways. Many of the desalination plants that supply water for agriculture were damaged or closed, either due to the war or to the oil spill. Air pollution from the war and the burning oil wells affected areas of the shrub and desert where nomad tribes herd goats, sheep, and camels. In 1990 the Eastern Province of Saudi Arabia had approximately 70,000 sheep, 20,000 goats, and almost 10,000 camels (Sadiq and McCain, 1993). Most of the animals were moved southwards before the war and were kept in the southern parts of Saudi Arabia as the war started and the oil wells were set on fire. More than 80% of the livestock animals in Kuwait, mostly cattle, sheep, and goats, died between the Iraqi occupation in August 1990 and the ceasefire in March 1991 (Loretz, 1992). The sheep were highly contaminated by soot and oil, and some died. The sheep seemed to have suffered more than other livestock and several farmers connected this with the sheep grazing on the highly contaminated vegetation. Damage also resulted when animals stepped on mines or unexploded cluster bombs, which littered large parts of the desert at the end of the war.

Seven years after the war, the agriculture system in Kuwait has recovered in most areas (Green Cross International, 1998). Sheep are grazing in many parts of the desert, and there are increasing efforts to regulate the amount of land used for grazing to protect the available ground cover of the desert. Iraq has enough agriculture resources to sustain its population, but for sufficient productivity, crops require water, fertilizers, and pesticides. The UN embargo had numerous effects on Iraqi agriculture including the banning of the import of many of these chemicals. The Gulf War also resulted in a labor shortage in the agricultural sector as the majority of the male population between the ages of 15 to 45 was drafted into the army. Data on the current status if Iraqi agriculture is not available.

4.5.10 Groundwater

The surface of the groundwater in Kuwait, northeast Saudi Arabia and Iraq is often found near the surface of the ground. In most cases this water has a high salinity and cannot be used for drinking or domestic purposes. Somewhat salty water can be used for irrigation and to mix with desalinated water to make it potable. Fresh groundwater is only found in a few areas and Kuwait's two natural fresh groundwater reserves are located near the major oil fields in the north of the country (at Raudhalain and Umm Al-Aish).

There is a significant danger that oil from the oil lakes as well as petroleum used in the extensive network of trenches may gradually percolated to the groundwater reservoirs and contaminated the aquifers. In addition to the potential problems caused by the petroleum, there is a risk of contamination of the freshwater by salt. Approximately 20 million m^3 of sea or brackish water was used during the firefighting-operations. As the soil and ground material above the reservoirs is contaminated with oil and salt, this pose a risk for a long time ahead as these pollutants may slowly be transported with infiltrating rainwater into the groundwater aquifers (Omar et al., 2000). However, more precise information on the impact of oil pollution on the groundwater is scarce. Groundwater samples from 1993 indicated minor oil pollution (Hadi, 1993). However, this pollution may have contaminated the reservoir before the Iraqi invasion. A more recent study of the distribution and level of hydrocarbon in the groundwater in Kuwait indicate that 36 out of 42 investigated wells were free from detectable levels of petroleum hydrocarbons. The remaining six wells showed some petroleum contamination (Al-Awadi et al., 2001). It should be noted that natural oil contamination of groundwater might occur in areas with large deposits of petroleum. The Kuwaiti Institute for Scientific Research (KISR) monitors the status of the groundwater in Kuwait. These studies indicate that the fresh groundwater at Umm Al-Aish show significant hydrocarbon contamination (Green Cross International, 1998). Loss of this aquifer means the loss of approximately 40% of Kuwait's strategic supply of natural freshwater. The hydrogeology of the region and other factors indicate that the contaminants known to be present at Umm Al-Aish cannot normally migrate in the direction of the nearby Raudhalain aquifer. However, overuse of the Raudhalain aquifer could draw contamination from Umm Al-Aish. As freshwater is a scarce and valuable resource, and as the petroleum hydrocarbons from the oil lakes migrates deeper and deeper every year, the risk for contamination of groundwater aquifers is regarded as one of the greatest concerns in Kuwait nowadays (Green Cross International, 1998).

4.5.11 Mines and Munitions

Shortly after the liberation, the Ministry of Defense in Kuwait estimated that the Iraqi troops deployed approximately 1 million landmines during the occupation. These mines, intended for soldiers and tanks, were spread over 60% of the Kuwaiti land area. After some time a new assessment was presented now estimating the number to about 2,4 million. Extensive clearing efforts were undertaken the years after the war and in 1997 most of the landmines had been destroyed. However, still the Ministry of Defense estimate that over 30,000 mines have not been cleared, and there are occasional accidents involving these mines, often along the border between Kuwait and Saudi Arabia. A total of 1,646,926 landmines had been cleared by September 2000, including 1,078,966 antipersonnel mines and 567,960 antivehicle mines (see homepage for "International campaign to ban landmines" http://www.icbl.org/lm/2001/kuwait/#fn5190).

The total area impacted by troops, bombs, and other war activities is estimated to be at least 40,000 km^2. It has been estimated that in total about 120 000 tons of ammunition, such as grenades, bullets etc. were used by both sides during the war (Barnaby, 1991). The environmental effects of the ammunition left behind by the Iraqi forces have not been investigated. It was reported that the Allied Forces dropped a total of about 84,200 tons of bombs (Sadiq and McCain, 1993). According to independent expertise, this seems to be a relatively low figure considering the large quantities of ammunition used to bomb the minefields. The Allied bomb-raids were manly intended for Iraqi ammunition supplies, which were believed to be quite extensive. It has been estimated that up to 20-30% of the bombs and grenades may not have exploded and were left behind as "live ammunition", scattered over Kuwait, northeast Saudi Arabia, and southern Iraq. The Kuwaiti authorities reported that a year after the liberation, over 10,000 tons of "live ammunition" have been found and been destroyed. Information from Saudi Arabia and Iraq is not available. However, significant quantities were probably left here too. Much of this ammunition was probably covered by sand in the years after the war.

4.5.12 Destroyed Vehicles, Equipment and Wastes

About 70% of the Iraqi armor and artillery used in the war was destroyed. This means that approximately 3,000 tanks and 2,100 artillery were left on the battlegrounds. In addition, large numbers of vehicles used by the Iraqi occupation forces were damaged or destroyed. Large numbers of bombed and burnet out vehicles, tanks, trucks and other equipment were scattered in the desert at the end of the war especially along the main road from Kuwait City north to the Iraqi border. Here heavy bombing destroyed thousands of military and civilian cars, trucks, buses, tanks and other vehicles which were left littered along the road.

As mentioned above (Section 4.5.11), at least 120,000 tons of ammunition was used in the war. At least 60,000 tons or about half of this weight consists of metal, plastic and other material, which is spread out in the environment after the explosions. Drifting sands probably buried most of this material rather quickly after the war.

Much of the Kuwaiti infrastructure was destroyed or damaged during the occupation or liberation. This includes domestic property as well as industry such as power stations and the power distribution, water supply including desalination plants, television- radio- and telecommunication-centrals, the international airport, ports, etc. Many factories, refineries, warehouses, banks, museums, and hospital were sacked or set to fire. The most significant damage was to the oil and gas production facilities. Iraqi troops placed explosives on wellheads and oil transfer and storage facilities, and during their retreat they detonated many of the explosives causing considerable damage to the facilities. Approximately 80% of the facilities had to been replaced after liberation. It took Kuwait about seven years to fully restore the oil production infrastructure (Green Cross International, 1998).

The Allied forces stationed in the northeast of the Saudi Arabia desert, consisted of more than half a million troops. These soldiers spent 4-8 months in the area, sometimes longer. It was estimated that these soldiers generated 250,000 tons sewage and domestic waste. The troops generated nearly 10 million of waste during the preparations for the Kuwaiti liberation.

4.5.13 Persistent pollutants

Several more or less persistent chemicals were used in different applications during the war in 1991 and much of these were released as pollutants. However, it is extremely difficult to collect information from the military on additives and chemicals that are used as most such information are military secrets. Halones, which is a group of carbon-flour-brome-compounds, were used to reduce the risk of explosion of the fuel tanks of the military aircraft. The halones was added as the fuel in the tanks was consumed, to prevent the formation of explosive gas mixtures. It is impossible to estimate the total amount of halones used in the war, as this kind of information is classified. However, a hypothetical calculation show the following: The Allied air crafts did approximately 110,000 missions. If each mission consume 25 kg of halones, the total amount of these substances used during the 43 days of air raids was almost 3,000 tones or nearly 10% of the total annual global discharge of halones. Freon is a related group of persistent compounds, which also is a well known greenhouse gas. Freon was used as an additive to the fuel used by the Stealth-bomber, primarily to reduce particulate emissions so that the plane should not be undetectable by radar. The amount of freones used in the aircrafts is also classified but 44 F-117 Stealth-bombers were used in the Gulf War (Sadiq and McCain, 1993).

The allies stationed in northeast Saudi Arabia used insecticides against flies and mosquitoes. No information is available on the type or amount of insecticides used or what kind of health problem they caused.

Concerns also exist regarding the problem of depleted uranium. Depleted uranium has a number of peaceful applications such as counterweights or ballast in aircraft, radiation shields in medical equipment used for radiation therapy and containers for the transport of radioactive materials. Due to its high density, about twice that of lead, and other physical properties, depleted uranium is used for military purposes; in military armor and ammunition designed to penetrate armor. The main sources of depleted uranium during the Gulf War are the uranium-tipped antitank shells used by the Allied troops in M-1 tanks and A-10 fighters. After the explosion of the shell, uranium is dispersed into the air in the form of oxidized particles and can be dispersed within a radius of several kilometers. The dust may be inhaled, or enter the food chain either directly through the ingestion of dust on food or by plant uptake from surface water, via the use of surface water for drinking or following migration of uranium into local groundwater aquifers, which may be used for drinking water or crop irrigation. Potentially depleted uranium has both chemical and radiological toxicity with the two important target organs being the kidneys and the lungs. Little information regarding the situation in the region is available. However, one study of soil samples from the Kuwaiti desert found that uranium concentrations ranged from 0.3 μg/g to 1.85μg/g (Bou-Rabee et al., 1995). The average value of 0.7 μg/g is lower than the world average value of 2.1 μg/g for surface soils. The total per capita intake of uranium via inhalation by Kuwaiti inhabitants was estimated at 0,05 Becquerel, which is <0,2% of the recommended annual limit on intake for members of the general population (Bou-Rabee, 1995).

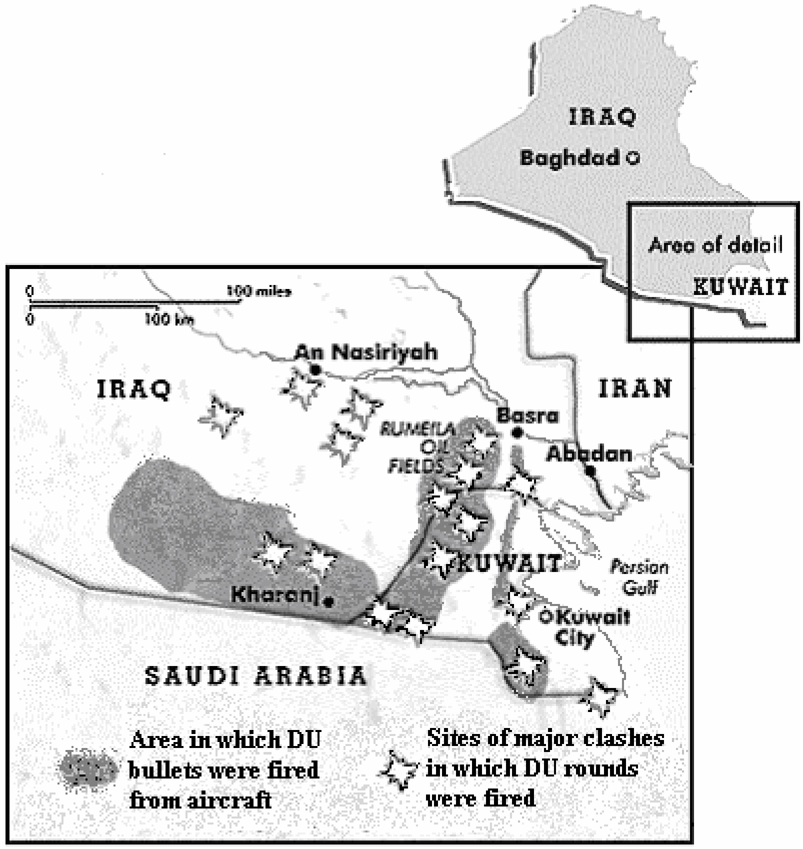

Figure 16. Map showing the areas of major air attacks and troup clashes during the war.

Another potential environmental issue that has been debated after the war is the release of PCBs in hydraulic oils. As mentioned above, large numbers of Iraqi tanks and artillery guns, most of them produced in the Soviet Union, were destroyed in the war. Almost 3,000 tanks and 2,100 artillery guns was destroyed and left in the desert. The hydraulic oil of these tanks and guns reportedly contain PCBs. This has later been confirmed by analysis. Any quantitative information about the amount of leaked PCB from the tanks is not available. However, assuming that one armored tank contains 300 kg PCB, and an artillery gun 200 kg PCB, the total amount of PCB leaked out in the desert would be 1,300 tons. This certainly is a significant quantity of a very persistent environmental pollutant.

Iraq had two nuclear reactors before the war in Al-Tuwatha, 20 km north of Baghdad. These Iraqi reactors were fueled by highly-enriched uranium bought from Soviet Union and France. As the fuel in the reactors core were consumed, radioactive fission products were produced. The amount of radioactivity that was present at the time of the war depends how long the fuel had been used. During the American bomb raids before the land invasion in 1991, both reactors were destroyed. American sources claimed that the power plant was used for production of nuclear weapon, but Iraq said it was only used for production of radioactive isotopes for medical purpose. Information about the amount of radioactivity in the reactors is not available, but taking into account the long time they had been running, a considerable amount of radioactivity could have been produced. As the reactors were bombed radioactive isotopes, mainly Cesium-137 and Iodine-131, may have been spread in the area. Once in human organs, these elements produce radiation and exposure to this radiation may induce cancer. Whether this cause a threat to the people and the environment in the surroundings is not clear. Like other aspects of the war, information on the possible release of radiation during or after the bombing of these reactors is not available.

Several studies have been carried out to find techniques and technologies to clean up the contaminated soil. In July 1994, a joint project between Kuwait Institute for Scientific Research (KISR) and Japan Petroleum Energy center (PEC) was initiated, testing three different biological technologies (Balba et al., 1998). Bioremediation is effective in treatment of petroleum hydrocarbon contamination. To enhance microbial growth the adequate microorganisms must be present and the physiological environmental conditions must be right. Even if 82-90,5% of the total alkenes was removed, depending of the bioremediation method used, the process was energy- and water intensive and was considered not cost effective for the entire quantity of material. Calculations showed that treatment of all the soil and other ground material affected by oil lakes would cost nearly US$ 1.3 billion (Shouse, 2001). Other research has shown that passive, or natural, bioremediation can help to recover contaminated areas. Experiments and observations showed the presence of large cultures of surface-associated oil-degrading microorganisms (Obuekwe and Al-Zarban, 1998) in the contaminated areas. Plants belonging to the family Compositae that were growing in oil-polluted sand always had white clean roots and the soil immediately adjacent to the plant was also clean while sand nearby was still polluted (El-Nemr et al., 1995). Studies showed that oil-utilizing microorganisms are associated with roots and cultivation of selected crops on the contaminated area could stimulate the degradation of the oil.

4.6 Impacts in the Marine Environment

The oil spill in the Arabian Gulf was no doubt the largest ever released into the marine environment anywhere in the world. The exact quantities are difficult to assess but estimates vary between 1 and 1.7 million metric tons (see for example Al Rabeh et al., 1992; Sadiq and McCain, 1993). MEPA of the Saudi Arabia has presented an assessment of about 1.4 million tons (Tawfiq and Olsen, 1993). The reason for the large variation in the different estimates is that it was often impossible to know when a particular spill started. In some cases the spill was discovered from aerial surveys or satellites photos several days after it had started. In addition, many of the spills occurred as the oil was burning on land, and it is impossible to know precisely how much of the oil that was burned. Oil was released from a number of sources. However, the main sorces were three oil export terminals as well as several tankers that were berthed or anchored in the area surrounding these terminals. The single largest spill came from the Sea Island Terminal at Mina Al-Ahmadi (Lindén and Husain, 2002). On January 20, valves were opened at the terminal and 70 to 80 thousand tons of oil were pumped out each day for about one week. This spill was stopped due to allied precision bombing on January 28, although minor spills continued also after this date. It has been estimated that between 800 and 900 thousand tons of oil were released into the sea from the area of the Sea Island terminal. Other oil spills occurred from different sources in the Mina Al-Ahmadi harbor area. These were estimated to about 300 to 500 tons per day, in total about 20 thousand tons. Oil was also released from the refinery at Mina Abdalla in southern Kuwait and from the terminal at Mina Al-Bakr in southern Iraq. These spills may have consisted of 100 thousand tons or somewhat more. As mentioned above, significant spills were also released from the tankers along the coast. It is estimated that about 600 thousand tons of oil came from these ships. The largest amounts came from 4 tankers at Mina Al-Ahmadi and Shuaiba.

The Gulf War oil spill impacted primarily the southern coasts of Kuwait and the Saudi Arabia coasts north of Abu Ali, which is located about 400 km from the source. For the Saudi Arabia shoreline alone, it is estimated that 640 km have been oiled (Tawfiq and Olsen, 1993). The spill was larger than any previous spill and caused dramatic damage to intertidal flora and fauna. However, the damage appears to have been short-term. In sub-tidal areas, very little significant damage to plants and animals was noted. The populations of seabirds and waters were also affected by the oil spill. Particularly the populations of species such as cormorants were severe. Significant impacts were observed in the populations of prawns in the northern and central parts of the Gulf. However, it appears that the main cause of these effects was low ambient water temperature as a result of heavy smoke and soot particles from the burning oil fields.

4.6.1 Effects of Petroleum in the Marine Environment

The statistics show that the number of oil spills, particularly larger spills, has decreased significantly in the last decades (ITOPF, 2003). There has also been a clear trend towards decreasing total quantities of oil released into the marine environment (see Tables 11 and 12). However, oil spills from loading and shipping continue to occur, and despite the huge quantity of information regarding the toxicological and environmental consequences of oil spills, each new spill raises similar worries about long-term and more or less irreversible damage to marine life. Each spill raises expression about of concern from the public, media, governments, and environmentalists. And each spill raises scientific questions about acute and long-term biological and ecological impacts. It is a fact though, that the impacts of oil and petroleum hydrocarbons have been subjected to more research and studies than any other marine pollutant. Although each spill has its unique characteristics and features when it comes to type of oil, location, timing, release patterns and fate, features that makes exact predictions regarding impacts difficult, the impacts of petroleum hydrocarbons in the marine environment are generally very well known.

Table 11: Quantity and number of oil spills 1970-2002 (ITOPF, 2003)

Year	Quantity of oil spilt (tones)	Number of spills 7-700 tones	Number of spills >700 tones
1970	301,000	6	29
1971	167,000	18	14
1972	311,000	49	24
1973	166,000	25	32
1974	169,000	91	26
1975	342,000	97	19
1976	369,000	67	25
1977	298,000	65	16
1978	395,000	54	23
1979	608,000	59	34
1980	103,000	51	13
1981	44,000	49	6
1982	11,000	44	3
1983	384,000	52	11
1984	28,000	25	8
1985	88,000	29	8
1986	19,000	25	7
1987	30,000	27	10
1988	198,000	11	10
1989	178,000	32	13
1990	61,000	50	13
1991	435,000	27	8
1992	162,000	31	9
1993	144,000	30	11
1994	105,000	27	7
1995	9,000	20	3
1996	79,000	20	3
1997	67,000	27	10
1998	10,000	22	4
1999	29,000	19	5
2000	12,000	18	3
2001	8,000	16	3
2002	82,000	n.a.	2

Table 12: Selected major oil spills (ITOPF, 2002).

Shipname	Year	Location	Oil lost (tones)
Torrey Canyon	1967	Scilly Isles, UK	119,000
Wafra	1971	off Cape Agulhas, South Africa	40,000
Metula	1974	Magellan Straits, Chile	50,000
Jakob Maersk	1975	Oporto, Portugal	88,000
Urquiola	1976	La Coruna, Spain	100,000
Hawaiian Patriot	1977	300 nautical. miles off Honolulu	95,000
Amoco Cadiz	1978	off Brittany, France	223,000
Atlantic Empress	1979	off Tobago, West Indies	287,000
Independenta	1979	Bosphorus, Turkey	95,000
Castillo de Bellver	1983	off Saldanha Bay, South Africa	252,000
Assimi	1983	55 nautical. miles off Muscat, Oman	53,000
Odyssey	1988	700 nautical. miles off Nova Scotia, Canada	132,000
Khark 5	1989	120 nautical. miles off Atlantic coast of Morocco	80,000
Exxon Valdez	1989	Prince William Sound, Alaska, USA	37,000
ABT Summer	1991	700 nautical. miles off Angola	260,000
Haven	1991	Genoa, Italy	144,000
Aegean Sea	1992	La Coruna, Spain	74,000
Katina P.	1992	off Maputo, Mozambique	72,000
Braer	1993	Shetland Islands, UK	85,000
Sea Empress	1996	Milford Haven, UK	72,000
Prestige	2002	Cap Finisterre, Spain	77,000

Oil is a complex mixture of hydrocarbons of varying toxicity depending on its chemical composition. In general terms, the absolute toxicity of petroleum hydrocarbons are greater for the high-molecular-weight compounds, for example 3- and 4 ring aromatics. However, the low-molecular-weight compounds and the mono-aromatic fractions cause most of the toxic effects that can be observed in water living organisms. This is due to the fact that these compounds are more water–soluble than the heavier fractions. Besides the physiologically toxic effects of petroleum hydrocarbons, there I also the physical hazard of spilled oil. Oil smothers birds, marine mammals, and littoral and inter-tidal organisms. Even if the toxic components are of insignificant levels, the animals may die because they drown or they spend too much time clean themselves, and by this loose too much energy. In the Arabian Gulf, oil and oil-related chemicals enter the marine environment from a variety of sources. These sources include both chronic discharges, which originate from various human activities like transportation, industries, refineries, wastes and natural seepage, as well as accidental spills (Literathy et al., 2002).

4.6.2 The Degradation of the Oil

In the Gulf, as elsewhere in the marine environment, oil is subjected to a number of weathering processes, all of which contributes to the gradual disappearance of the oil (see Figure 17). The speed of the weathering processes depends to a large extent on various environmental factors such as temperature, availability of oxygen etc. It is well known that under normal conditions in the Gulf, oil weather rapidly. One important weathering process is the evaporation of volatile components of the oil to the atmosphere. It has been estimated that between 30 and 40% of a Kuwaiti crude oil evaporates to the atmosphere during one to two weeks under normal conditions in the Gulf (Al Rabeh et al., 1992). The oil that contaminated the Gulf in 1991 was released under relatively calm weather conditions. As a consequence, relatively small volumes were mixed into the water column. Instead most of it formed a slick on the surface from where the petroleum hydrocarbons in the slick evaporated to the air. However, over time an emulsion was formed. The oil droplets in the emulsion picked up particles in the water, suspended sediments, detritus etc, and started to sink. However, a significant fraction of the oil remained at the surface and arrived to the beach either as a slick or as a water-in-oil emulsion.

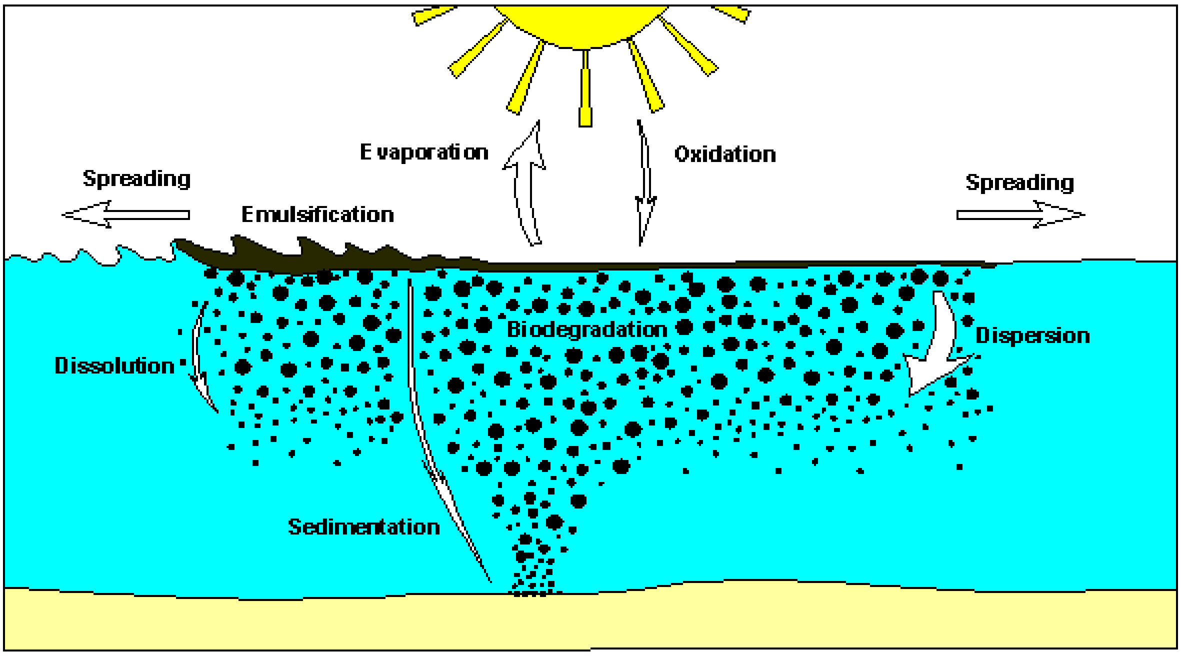

Figure 17. Fate of oil spilled at sea showing the eight main processes that cause oil to weather (ITOPF, 2002).

It is impossible to assess with any certainty the quantities that were lost to the atmosphere or to the water column before the oil arrived to the shores of Saudi Arabia. However, several estimates were made of the quantities that ended up on the Saudi beaches. Attempts to estimate the quantities of this oil gave varying results. It is likely that less than 50% of the original quantities of oil actually ended up on the beaches. Evaporation may have removed 30 to 40%. Based on measurements from other spills it can be estimated that 10 to 20% of the oil sedimented to the seabed. Other processes such as dissolution removed small amounts. Analysis of the oil on the beaches in Saudi Arabia showed that it contained 40 to 70% water (Sadiq and McCain 1993). This, of course, contributed to make the oil spill appear larger than it actually was.

Table 13: Factors controlling weathering of petroleum in the aquatic environment (ITOPF, 2002; Literathy et al., 2002)

Process	Factor
Spreading	Viscosity of the oil.
Evaporation	Oil surface and air temperature, wing speed and wave action, solar radiation.
Dispersion	Surface-active agents, wave action, salinity.
Emulsification	Asphaltene content (greater than 0.5% tend to stable emulsions).
Dissolution	Water temperature, wave action, salinity, adsorptive of particulates in water, solubility, surface-active agents.
Oxidation	Solar radiation/energy, dissolved oxygen, water temperature.
Sedimentation	Water temperature, particle size, density, currents, wave action.
Biodegradation	Microbial activity, bioresistancy and solubility, level of dispersion, water temperature.

4.6.3 Where did the Oil End Up?

Most of the oil was transported by winds and currents southwards along the coast of Saudi Arabia where most of the oil stranded. Smaller amounts, probably most of which was released from the terminal at Mina Al-Bakr in Iraq, was transported towards the east and south east along the coast of Iran where it, according to media reports in Iran, resulted in heavy impacts. More specifically the coast north of Bandar Khomeini was contaminated with this oil (Twarfiq 1991). Oil contamination was also reported from the shores of Bahrain and Qatar (El-Baz 1992). This oil may have been released from other sources including ships that were shot at in other parts of the northern Gulf. The oil hit the coastline of Saudi Arabia in connection with a period of spring tide in the end of January and early February (see Table 14) (Al-Rabeh et al., 1992; Gundlach et al., 1993; Twarfiq and Olsen, 1993; Al-Hinai et al., 1993). As a result, the oil ended up high up on the beaches, other in the land vegetation around the high water mark. In some areas, as a result of the high water table, the oil was transported into lagoons and wetlands that under normal circumstances would have been protected from the oil.

Table 14: Dates of oil sightings along the Saudi Arabia coast (Al-Rabeh et al., 1992).

Location	Date
Khafji	January 25, 1991
Safaniya	January 29, 1991
Ras al Ghar	February 8, 1991
Abu Ali Island	February 14, 1991

4.6.4 Beaches

The oil on the beaches in Saudi Arabia had lost most of its toxic components long before arriving to land. Hence the oil was more an aesthetic and physical problem than a problem of toxicity. However, mortality was reported among organisms from the upper intertidal zone where most of the oil was accumulated (Prena, 1996; Hayes et al., 1993). In most cases the oil had contaminated down to about 10 cm, although in some areas with porous beach material, gravel, course sand, it had penetrated down to some 50 cm (Hayes et al., 1993). Oil that has penetrated into such depth require many year for degradation, mainly because oxygen is limited. In shallow lagoons, wetlands and flats covered with vegetation, the oil caused considerable damage. This damage was however caused primarily by the physical characteristics of the oil. If the surface of leaves and steams are covered by oil, gas exchange is limited and the plant may die from suffocation. In addition, the black surface may cause temperature effects, as the black surface tends to accumulate more heat for the sun radiation. Investigations show both these effects on the vegetation affected by the oil. The major part of the vegetation (dwarf mangroves, salicornia and other succulent plants) on the wetlands along the affected coast in Saudi Arabia was destroyed by the oil. One area that was studied carefully was the Jubail Marine Wildlife Sanctuary, an area along about 100 km of coast between Ras az Zaur and Abu Ali Island (Krupp and Khushaim, 1996; Hayes et al., 1993). Of about 225 km^2 of wetlands, about 22% was destroyed totally. On an area of about 380 ha, less than 1% of the vegetation survived and more than 1000 tons of dead plant material was found in the area after the spill. In 2001 around 80% of the sandy shores was recovered, although oil still residues may be found buried beneath the sand (Barth, 2002).

The oil on the beaches was exposed to the natural cleaning processes from water and wind. In the lower parts of the beaches, most of the oil was removed relatively rapidly. However, higher up on the beaches the oil remained and was transformed into tar. In these areas a lot of fauna, mainly crabs, amphipoda and molluscs, were killed by the oil (Prena 1996; Hayes et al., 1993). Investigations showed that 50 to 90% of these animals died within a few months after the spill hit the coast. In December 1991, investigations showed that natural clean-up processes had removed most of the oil from hard surfaces and decreased the quantities considerably in areas with sand and mud (Watt et al., 1993). The oils and tar that remained had been covered by growth of algae. About three years after the spill most of the fauna had re-colonized the lower sections of the beach, and the recovery on the upper sections was underway. The species diversity in the affected areas was now 50 to 100% of what it was in control (not contaminated) areas. However, traces of oil spill remained on the beaches seven years after the war. Weathered and underground oil were still present on some beaches and these benthic communities had not yet recovered to their pre-war equilibrium (Green Cross International, 1998).

The large-scale clean-up that was carried out after the spill in many areas did contribute to increasing the damage. Investigations in 1991 indicates that areas which had been carefully cleaned, particularly using high pressure flushing and where the upper part of the sediment had been removed, the recovery of the fauna took significantly longer time than if the oils had been left for natural degradation or only partially removed (Watt et al., 1993).

Figure 18. Oil spill on the Saudi Arabian coast, May 1991.

4.6.5 Mangroves

The mangrove trees provide shelter and cover from predators and the root of mangrove trees trap fine-grain sediment to form a nutrient rich substrate for the development of a complex, productive community of organisms. These root systems are especially sensitive to contact with oil. There has been tremendous pressure on the few remaining mangrove stands in the Arabian Gulf, and because of their importance and sensitivity, the Saudi Arabian Meteorology and Environmental Protection Administrator (MEPA) chose to designate mangroves as the impacted community with the highest priority for protection, cleanup, and restoration. During the shoreline survey conducted just after the oil spill mangrove branches, leaves, and pnematophores were found to be coated with oil due to the high tide elevation (Sadiq and McCain, 1993). Other plants such as holophytes were also heavily oiled. During early April 1991, yellowing and defoliation of leaves were noted. During the acute phase, attempts were made to clean the contaminated mangroves by flushing water over the plants. This was done for example in the Gurman Island. In most cases these attempts were however unsuccessful and most of the mangroves died. Attempts were made to rehabilitate the areas between Ras az-Zaur and Abu Ali Island where the vegetation had died. The rehabilitation was done through artificial replantation of mangroves and salicornia (Böer 1996). Replantation of areas that were the oil was still present was not successful. However, if the contaminated soil had been removed and exchanged with clean soil, the survival was good.

Attempts were made to rehabilitate the areas between Ras az-Zaur and Abu Ali Island where around 50% of the trees were affected by the oil and 30% had died off. The rehabilitation was done through artificial replantation of mangroves and salicornia (Böer 1996). Replantation of areas that were the oil was still present was not successful.

However, if the contaminated soil had been removed and exchanged with clean soil, the survival was good. Natural regeneration started two years after the impact and (Barth, 2002). Benthic organisms colonized the sediments and broke the surface tar crust and allowed oxygen to penetrate into the sediments. Even at severely damaged sites three to five years after the impact new seedlings had re-colonized the area, and in 2001 most sites in the area are aerobe and well bioturbated (Barth, 2002). The only signs of the impact are some remains of dead plants and very few tar residues.

4.6.6.Salt Marshes

Salt marshes are generally considered highly productive communities and are important feeding grounds for birds and other animals (Krupp and Jones, 1993). Salt marshes grow on mudflats and are composed of halophytic plants that are capable of withstanding inundation by seawater. Due to the extensive intertidal zone and the high tides in March 1991, salt marshes as the prominent upper shore biota were most severely affected by the oil resulting from the Gulf War. The estimated amount of oiled sediment in these marshes after the 1991 oil spill was 677,700 m^3 (Sadiq and McCain, 1993). Most of the benthic fauna such as crabs, snails and other invertebrates as well as halophytes were destroyed after the oil settled along the shores. In 2001, ten years after the oil spill, the salt marshes show the heaviest impact compared to other ecosystem types along the Saudi Arabian Gulf coast (Barth, 2002). The main reason for the delayed recovery is the absence of physical energy, wave action, and the anaerobic environment caused by cyanobacteria, which forms impermeable mats. At such sites even ten years after the oil spill liquid oil is still present in the upper sediments.

Figure 19. The oil spill affected most of the salt marshes along the Saudi Arabian coast (May 1991).

4.6.7 Sediment and Seawater Quality

Two sources cause seawater and sediment contamination; atmospheric fallout and the oil spill. Predictions came early that the oil would pollute substantial water masses in the water column of the Gulf. Oil droplets and water-soluble fractions of the oil affected the water column mostly during the fist week of the spillage. As the slick slid across the sea surface these toxic hydrocarbons spread into the waters beneath, and killing marine organisms living there. At a depth of around 10 cm the concentration of hydrocarbons was around 2 parts per million, and half this concentration at 20 cm (McKinnon and Vine, 1991). The studies of the acute and long-term effects of the Gulf War oil spill showed relatively little impacts in benthic sites along the Saudi Arabia coast, even in shallow waters (Jones and Richmond, 1992; Jones et al., 1996). In fact, even in the intertidal zone much of the fauna survived despite the large volumes of oil. It appears that the oil that had deposited on the substrate at low tide was lifted off at high tide and the organisms in the sediment could continue feeding

Studies from different subtidal areas along the Saudi Arabian coast on sand, mud and rock bottoms and in sea-grass beds showed minor or no effects at all among the fauna and flora at 1 to 6 meters depth. The species diversity and the abundance were unaffected on the seabed, also in areas where large volumes of oil has been drifted through. The explanation is that simultaneous to the contamination of the oil to the sea, most of the toxic compounds had been lost to the atmosphere or had undergone microbial degradation. Acute levels of toxicity probably only occurred within the first meter of the water column. But the daily vertical migration of many planktonic species is likely to have increased the death rate. After the first week the oil spread more slowly as it weathered and became thicker. The oil drifted more or less as an intact film with relatively little dispersion of hydrocarbons into the water column. Toxicity levels in the water column beneath the slick were much less than during the initial period, reducing the impacts on plankton, but posed a serious hazard to larger marine life such as birds and turtles. Dive survey showed that relatively little oil had sunk to the bottom. Analysis of the content of metals in the surface water and in the floating oil indicated a considerable fall-out of metals from the atmosphere (Habashi 1991, quoted in Sadiq and McCain 1993, Husain 1995). Especially the levels of iron, lead, copper and zinc were increased. The concentrations of these metals increased with time and this was taken as evidence that they originated from the burning oil oils in Kuwait.

The investigations along the beaches after the war confirmed what has been observed earlier following oil spills in the Gulf. The results show that other environmental problems than oil cause significant effects on the ecosystem (Price et al., 1993; Watt et al., 1993; Sheppard et al., 1992). Hence the indiscriminate dumping of garbage along the beaches and in the Gulf waters, cause damage to birds and turtles as well as a lot of invertebrates and plants.

4.6.8 Coral Reefs

The coral reefs of the Persian Gulf are the most important repositories of biodiversity in the region and also among the most productive offshore ecosystem. Shortly after the war concerns arose that these ecosystems may have been adversely impacted from oil and/or smoke from the burning oil wells. The sensitivity of coral species to oil and petroleum hydrocarbons is reported to be quite variable and at least one species

(Diploria strigosa) is known to be relatively tolerant to disperse oil (Literathy et al., 2002). Coral reefs in the Gulf are of interest because they represent one of the most northerly-located reefs in the world and survive under extreme environmental conditions. The coral reefs in the Gulf are generally regarded as “marginal coral reefs”, which means that they survive in conditions close to their tolerances. Therefore, they are highly vulnerable to human-induces stressors including the toxic effects of oil and its constituents. Several investigations were carried out to study the impact on the coral reefs along the coast in Kuwait and Saudi Arabia (Downing and Roberts 1993, Jones and Richmond 1992, Sadiq and McCain 1993). The studies aimed to assess the extent of impacts due to toxic effects on the corals and the associated fauna and flora. Another factor to be studied was the effects of the low ambient temperature during 1991, which was the result of the large quantities of smoke in the atmosphere. Reef corals are particularly sensitive to environmental stresses and the reduced light and temperature could therefore have affected coral and reef growth. But the studies did not reveal any significant effects, particularly in the reefs off the Saudi coast. Some mortality that may be related to the oil was noted among corals in the reefs off the Kuwait coast. However, studies also showed obvious signs of recovery. Also the fish fauna appeared to have survived intact. Vogt (1995) actually recorded a significant increase in live coral cover of Saudi offshore and inshore reefs from 1992-94. In the reefs closer to the coast in Kuwait and Saudi Arabia, more damage was seen. However, this could have been caused by other factors than the oil.

4.6.9 Impact of Oil Fires on the Marine Environment

The National Centre for Atmospheric Research (NCAR) in Boulder, Colorado and University of Washington teams conducted solar radiation measurements and found that 10% of the sun’s radiation was transmitted through the thickest part of the super composite plume. About 75 to 80% of the sun’s radiation was absorbed and the remainder was scattered by the smoke in the super composite plume (Hobbs and Radke, 1992). Khordagui and Al-Ajmi (1993) reported a temperature drop up to 10°C in Kuwait and the northern Saudi Arabia. Browning et al. (1991) estimated a reduction in mid day temperature of 5-8°C at 250 km from the source and 1-2°C beyond 750 km. Increase in particulate and smoke density in the air resulted in a significant decrease in temperature. The temperature drop of 3-4°C in midday was observed during smoky days. In some cases a drop of 6-8°C was not uncommon. A significant drop in temperature was observed between February and September 1991 in Jubail, which is the Eastern part of Saudi Arabia, and in Bahrain (Suthers, 1991). This decrease corresponded to a drop of 25-45% in solar radiation in comparison to previous years. As a result of the thick smoke and the resulting decrease in air temperatures in the region, seawater temperature in the Gulf was considerably lower during 1991 as compared to previous years. The measurements of Mania Pier, about 250 km from Dhahran towards Kuwait showed a decline of 2.5°C in mean sea temperature in 1991. Fish as well as prawns and other organisms in the Gulf live close to their thermal tolerance limit. The tolerance of larval stages of fish is even more restricted than those of the adults (Sheppard et al., 1992). The drop of seawater temperature during spring-summer period of 1991 is likely to be the reason for most of the impacts on fish and prawns (see Section 4.6.11 below).

4.6.10 Sea Birds and Waders

The shallow coastal waters, shores and tidal flats of the Gulf are important resting and feeding areas for large numbers of migrating sea birds and waders. In fact, the shores of the Gulf are considered one of the five most important sites for migratory waders in the world. Several million waders migrate through the area each spring and autumn (Zwarts et al., 1991). In addition the beaches and islands along the coast are nesting areas for many species including cormorants, terns, herons and waders. Quite early during the war, there were fears expressed that the oil spills would cause very serious threats to these birds. The direct effects of oil on birds are twofold. First, direct oiling reduces the insulating properties of the feathers and second, direct intake of oil through breathing, skin absorption and, worse of all, preening (McKinnon and Vine, 1991). Not only direct contamination would cause mortality, but the fact that the oil killed large numbers of small animals, crustaceans and molluscs, on the tidal flats, would make it difficult for migrating birds to feed in the area. Observations of massive mortality among littoral invertebrates, particularly in the upper part of the intertidal, were confirmed through studies by Krupp and Khushaim (1996). The later assessments of the damage basically confirmed that very large numbers of bird were killed by the oil spills. At least 30 000 cormorants and grebes were killed during the acute phase (Symens and Suhaibani, 1993). This only includes the dead bodies that were found during the period January – April 1991. The actual numbers are therefore likely to be significantly higher as dead birds offshore tend to sink before they reach the shores. The ornithologists estimate that between 22 and 50% of the populations of several species of cormorants and grebes died as a result of the spill.

During the months of March through May, the normal number of waders on the shores of the Saudi Arabian Gulf coast has been estimated to be about 130 000 (Evans and Keijl 1993; Zwarts et al., 1991). Investigations made during this period in 1991 indicated less than 4000 birds in these areas, a reduction by 97% (Evans et al., 1993). In addition, at least 75% of the birds were oil contaminated. The missing birds were either dead or had migrated to other areas because of the presence of oil on the beaches, and perhaps more likely, the loss of food supply due to the absence of invertebrates on the shores. Other investigations (Harbard and Wolstencroft 1992) show that the number of waders along the Saudi Gulf coast in 1991 was about 25% of the normal figures in the spring 1991, and 35% in the winter 1991-1992 (see Table 15). The ornithologists conclude that may be about 100 000 waders were killed directly or indirectly by the oil spill in 1991. The population of terns appears to have been more successful in surviving the oil spill. No effects were found in the populations in Kuwait while a 22 and 28% reduction in the population numbers were reported in Saudi Arabia (Symens and Alsuhaibany 1996).

Studies of sub-lethal effects of the oil spills on the bird populations have also been reported. One such investigation was looking at the relationship between oil contamination on the plumage and the body weight. The study showed that birds that had more than 10% of their plumage oiled, also had significantly lower weight than the birds that had not been oiled (Evans and Keijl 1993). This may be a sign that these birds have less chance of being able to complete their migration and breeding successfully.

Table 15: Comparison of shorebird populations utilizing the Saudi Arabian Gulf coastline before and after the war (from Harbard and Wolstencroft 1992)

Shorebirds	Before the war	Spring 1991	Winter 1991/92
Dunlin	116 000	2 856	17 121
Little stint	51 000	4 165	3 533
Lesser sand plover	28 000	5 885	3 766
Redshank	9 000	810	5 776
Ringed plover	8 000	326	456
Greater sand plover	8 000	75	1 279
Grey plover	7 000	1937	2 606
Broad-billed sandpiper	6 000	533	490
Curlew	6 000	762	2 658
Bar-tailed godwit	6 000	6 777	5 350
Black-tailed godwit	5 000	4	247
Curlew sandpiper	4 000	3 015	407
Terek sandpiper	4 000	3 591	1 727
Turnstone	3 000	1 885	1 321
Oyster catcher	1 000	347	645
Kentish plover	800	1 865	6 547
Greenshank	500	124	210
Sanderling	200	1 230	110
Total	263 000	36 187	54 240

Attempts were made to try to clean birds that had been contaminated with oil at the Jubail Wildlife Rescue Center. About 1500 birds, mainly cormorants and grebes were brought in for care and cleaning (Abu Zinada and Belcher 1992). Of these over 60% died before they could be released.

4.6.11 Fish and Shrimp Stocks

Fish can be affected by oil in a number of ways. One effect is the direct uptake of hydrocarbons through the gills or other thin epithelial tissues, or it could be ingested directly or indirectly through prey or feed contaminated by oil. However, this has only been observed in laboratory and in real situations in connection with an oil spill the concentrations of petroleum hydrocarbons in the water are usually to low and does not cause such effects on fish. There was a lot of public debate regarding the risks for serious consequences to the fisheries as a result of the oil spills and other damage on the marine Gulf ecosystem. Therefore several investigations of the impact of the oil spills on fish stocks and fisheries in the northern Gulf were carried out the years after the war. Fortunately no direct mortality of the fish stocks as a result of toxic effect of the oil slick or the well fires fall out has been shown. Most of the fishery species do not live in the upper layer of the sea as adults and could swim away to escape the slick. It is on the other hand more likely that the planktonic larvae stage or the eggs would have suffered such mortality, and massive mortality of egg and larval shrimp has been reported and direct poison could be one explanation (Mathews et al., 1993; Price et al., 1993).

However, it appears that the large volume of smoke, soot and particulate matter from the oil wells caused more severe impact on the marine environment than the oil slick did. The problem was that the smoke decreased sun radiation and temperature, both in the air and in the water. The average temperature during 1991 at the Saudi coast was about 2.5°C lower than normal. This was however the yearly average and during the most acute phase, February through June, the temperature differences were much larger than that. This is also the period for spawning of most of the marine fish and shellfish. As a result of less sun radiation and lower temperature, it can be assumed that the primary productivity during 1991 was lower than during a normal year. Therefore the observed effects on shrimp stocks (see below) are likely to be the result of changes in productivity in water, rather from oil contamination. Many of the organisms in the northern Gulf are living under temperature conditions close to their lowest tolerance level. Larval stages are frequently more sensitive than the adults and the spawning among many fish and shellfish species is highly dependent on the right temperatures. Spawning usually sets in when temperatures are increasing. Eggs and larvae of prawns (Peneaus) are under normal circumstances the dominating plankton in the Gulf during the period December through June. This was also generally the period during which the temperature was particularly low and when the smoke plumes were particularly heavy. Consequently there are several indications that the significantly lower water temperature, in combination with lower primary productivity caused negative impacts on the reproduction of several fish and shellfish species. There were fewer effects on the fish populations than on the prawns. However, there are indications that the spawning of the grouper (Epinephelus) was affected in the northern Gulf in 1991 and possibly also in 1992. But as this species has a much longer life than the prawns, it is more difficult to be able to clearly observe any effects based on the catches. High contents of heavy metal in fish and other marine living organisms have also been reported (Bu-Olayan and Subrahmanyam, 1996; Bu-Olayan and Subrahmanyam, 1997). The significant increase of primarily copper, lead and zinc concentrations in the marine organisms are due to the contribution from the oil spill. However, reliable data on organic and inorganic contaminants in commercially important fish species and shrimp of the Gulf are very limited. The available data suggest that organic pollution, including pesticides, of the Gulf is not a serious problem (Sadiq et al., 2002). Therefore, it is anticipated that consumption of fish or shrimp would not pose human health concerns with respect to organic chemicals. Among the inorganic pollutants, mercury and arsenic may be of some health concern. Several samples of fish and shrimp in the Gulf contain higher than permissible levels of these elements in seafood.

The Gulf War did not only have impacted the Kuwaiti's fisheries by affecting the biological resources, it also affected the fisheries infrastructure and organization. The Iraqis destroyed or stole most of the Kuwaiti commercial fishing fleet, and the harbor and the fish market were also severely damaged. The oil did also cause severe damage on the fishing equipment. Throughout the northern Gulf, there was large-scale damage on the traditional fish traps that are fixed on the tidal flats. These traps consist of wire mesh and sticks and when oil is drifting on the surface, it will smear the mesh. As a result the pressure from the water increase and the traps will usually collapse after some time. Of 35 trawlers before the war only 5 remained after the war. The oil spill as well as the mines and ordnance, impeded these from fishing throughout 1991. In November 1991 the small scale fishing using fish traps was taken up again involving 10 dhows and about 60 smaller boats (Sadiq and McCain, 1993). Fishing for prawns and fish was closed in Saudi Arabia during 1991 and when the prawn fishery started again in 1992, catches was only a fraction of what they were under normal conditions. Shrimp landings were only 25 tons in February 1992, compared to 3,700 tons in 1989 (Mathews et al., 1993). Saudi Fishing Company SAFISH estimates that the direct economic loss amounted to US§ 40 to 50 million. There were fewer obvious effects on the fish catches and the quantities reported were close to normal. But some species of both fish and shrimp are currently fished closed to or over the maximum sustainable yield (Green Cross International, 1998). The combination of high fishing pressures resulting from the fishery efficiency since the war and on-going negative environmental factors may lead to over fishing.

4.6.12 The Marine Turtle Population

There are nesting populations of two species of marine turtles in the area of the oil spill: hawsbill (Eretmochelys imbricata) and green (Chelonia mydas) (Miller, 1989; Miller et al., 1989). The total population of these species has been estimated to around 3500. The threats posed by oil slicks to turtles in open water are, by enlarge, similar to those facing other air-breathing marine mammals. The oil will clog the mouth openings and breathing canals. There are also reports that turtles mistake tar balls for something edible and getting them stuck in their throats. Turtles lay their eggs on sandy beaches and, as a result, are exposed to additional risks if a spill occurs in close proximity to nesting beaches or oil has washed up on these beaches. After the war, studies were made to assess how these populations had been affected by the oil spills (Al-Merghani et al., 1996). Special attention was concentrated on removing oil from known turtle nesting beaches and these attempts appear to have been successful. Pilcher (1992) reported that green turtles nested at rates and with hatching success, which was similar to the figures for the years previous to the spill. Hawksbill turtles showed significantly decreased hatching success. In addition, attempts were made to clean the beaches where these turtles are known to nest. Also, oil contaminated turtles were caught and cleaned. The studies showed that the number of nests and the hatching frequency among green turtles were normal compared with earlier years. For hawksbills the number of nests were normal but the hatching rate was much lower than normal. While under normal years the hatching rate is 80 to 90%, only 46% of the eggs hatched in 1991. This decrease in hatching rate may be due to the oil spills. The hawksbills feeds on benthic invertebrates such as bivalves etc., and petroleum hydrocarbons may have accumulated in these organisms. The green turtle on the other hand, is primarily herbivorous, feeding on plants. It is however possible that the observed effects have been indirect, for example the decrease of temperature as a result of the smoke plumes.

Since 1996, turtles have been seen sighted and recorded throughout Kuwaiti territorial water during every month of the year and the presence of these turtles has been taken as an indication that the environment of the northern Gulf is recovering from its previous degraded status (Meakins and Al-Mohanna, 2000). Attempted nesting has been observed on the mainland and on nearby islands, but it was not confirmed if nesting was successful.

4.6.13 Marine Mammals

One should expect that air-breathing mammals, such as whales, dugongs, and seals, would come into physical contact with oil if a slick were floating on the surface. Also inhalation of volatile hydrocarbons is likely to take place, but such exposure should under natural conditions be very short-term. The physical smothering in oil of the skin, eyes, mouth, nostrils, and air passages of these animals are probably of more concern. As the oil from a spill gradually weather, the amounts of biological available oils decrease steadily. Simultaneously the composition of the oil shifts towards those components that have low volatility and resist photo- and biodegradation. As this occurs the primary pathways of exposure change from direct intakes into routes involving the food supply. However, with the exception of a few unconfirmed reports relating observations of dead dugongs and dolphins to oil spill, no direct effects of oil on mammals have been reported from the Gulf. One should expect that air-breathing mammals would come into physical contact with oil if a slick were floating on the surface. Dugongs have been reported as far north as Ras al Zwar on the Saudi coastline; however, they are restricted to the area along the southern Saudi Arabian coast (Sadiq and McCain, 1993). Since the oil slick from the Gulf War oil spill was essentially limited the area north of Agu Ali Island, they were not exposed to any great extent to the oil spill. Estimations have been made that at least 93 marine mammals died in the western Arabian Gulf from late February through mid-April 1991 (Preen, 1991). These included 14 dugongs, 57 bottlenose dolphins, 13 humpback dolphins, 1 finless porpoise, and 8 unidentified cetaceans. The marine mammal losses reported above are relatively low in comparison to those reported during the 1983 Nowrus Oil spill caused by the Iran-Iraq war. Approximately 50 dugongs and over several times as many dolphins were found dead on the beaches of Saudi Arabia after that spill (Sadiq and McCain, 1993).

4.7 Clean Up of the Oil Spill

For Saudi Arabia, the 1991 Gulf War oil spill represented a crisis with enormous implications for Saudi Arabia's people, for the coalition armies defending its sovereignty, and perhaps more important, for the fragile Gulf ecosystem. During the acute phase after the spill, the first priority for response was focused on protection of oil production, desalination and power generation facilities. Saudi Arabia had increased its oil production by nearly 60% in an effort to prevent economic disruption of global oil markets, which made the protection important both military and economically. Many of the infrastructure facilities were important for the ongoing war, supplying fuel and water for the Allied forces and their operations (see Table 16). In addition, an arid country such as Saudi Arabia is extremely dependent upon desalination for its water supply, providing 70% of country's drinking water (Tawfiq and Olsen, 1993). Therefore the spill posed a threat not only to the military operations, but also to the basic continuity of life in the country.

Table 16: Strategic infrastructure facilities threatened by 1991 oil spill (Tawfiq and Olsen, 1993)

Strategic infrastructure	*Number of facilities*
Desalination plants	9
Power plants	4
Industries / Refineries	8
Ports	3
Naval bases	2

Efforts to protect vital facilities were extremely effective. Most of the strategic infrastructure facilities were secured from the oil slick by using booms and tidal traps. The planners decided early that the most effective response strategy was to concentrate efforts on removal of floating oil from the water. About ten recovery vessels were used in a rather limited recovery operation. The vessels were able to recover a total of 35,000 tones of oil and water mixture. The ongoing hostilities as well as floating mines posed a hazard and complicated the offshore operations. The large-scale recovery operations were therefore concentrated on various sites along the shoreline. The prevailing winds and currents concentrated the oil along the Saudi Arabia’s shoreline, which made the clean-up operation much easier. Offshore and shore side operations recovered a total of 200,000 tons of oil and water mixture which, when adjusted for water content amounted for 160,000 tons of oil, a record for oil recovery (Tawfiq and Olsen, 1993).

The oil spill contaminated about 640 km of the Saudi coastline. It was clear that the need for clean up far outstripped available manpower and equipment and that it was necessary to prioritize which areas would be cleaned up and which areas would have to recover naturally. Highest priority was given to areas of particularly importance for the environment and the ecosystem. Gulf islands such as Karan, Gurmah and Abu Ali provide important nesting habitat for turtles and sea birds. First priority was given to clean up these oil-soaked beaches since turtle nesting was due to begin during the late spring. Second priority was attached to the heavily contaminated mangroves on Gurmah and Al-Khafji. Oil was flushed from the mangroves using vast amounts of seawater. Surveys were undertaken immediately after the spill, and a costed proposal was prepared in which the costs of cleaning all of the contaminated shorelines was estimated to be $540 million (Tawfiq and Olsen, 1993). As the same time as this proposal was presented, some tests of clean-up methods revealed that natural degradation was taking place at some of the beaches. It was decided that only areas of particularly importance for birds and recreation would be cleaned up plus that oil at the risk of drift back to sea would be removed . Testing studies to determine the most effective and adequate clean-up method were also carried out (see table). These tests revealed soon that natural recovery would be less damaging to the environment than the proposed clean-up methods (Tawfiq and Olsen, 1993).

Figure 20 (see Figures 20-22 below).

Figure 20 (see Figures 20-22 below).

Figure 21 (see Figures 20-22 below).

Figures 20-22. The oil spill along the Saudi Arabian coast (April- May 1991). Oil spill combating operations are underway.

Table 17: Clean-up projects completed as of January 1993 (Tawfiq and Olsen, 1993, from: MEPA, 1991)

Clean-up site	Action(s) taken
Karan Island	Clean-up of oiled sand on beach
Gurmah Island	Mangrove clean-up, using high volume seawater sprinkers and skimming of freed oil
Al-Khafji	Clean-up of mangrove nursery (as above)
Dawhat ad Dafi	Clean-up of oiled shoreline, sand, sea grass and debris
Musallamiyah Bay	Test of oil removal methods
Jabal An Nuquriyah	Salt marsh cleaning
Masharabah	Methods test of salt marsh clean-up
Dawaht Sulayq	Methods test of salt marsh clean-up
Manifah	Test of DE-SOLV-IT for shoreline clean-up with water jetting
Jazirat al Toyor	Test of DE-SOLV-IT and high pressure, hot water for cleaning rocky shoreline
Jazirat Al-Maqta	Clean-up of oiled island sand and rock shoreline near Ras Al Mishab with environmental release agent and seawater jetting
Abu Ali	Clean-up of beach recovery pits
Mardumah	Beach clean-up with tilling

4.8 Human Health Aspects

The Iraqi invasion and occupation of Kuwait did not only caused severe environmental damage; it also produced a human tragedy of death and injury, torture, terror and trauma. There have been countless stories of cases where the general principles of human rights were seriously violated. The military aggression was aggravated by its sudden onset, the relatively high casualty toll, and the psychological unpreparedness of the population. Many Kuwaiti families had to flee to Saudi Arabia and other neighboring countries. One has also taken into account the more long-term impacts resulting from a damaged infrastructure, when hospitals and other nursing institution were destroyed, when clean water and medicines were not available, or when the sewage water was not cleaned properly. It is also necessary to taken into consideration the long-term psychological impacts of the affected population, injuries that is not only apparent as relatively well-known symptoms of stress, but also as a serious change of attitude in the relation to society and other human beings. It is impossible to provide a comprehensive picture of these problems. Information is often inaccessible, partly because the legal settlements after war are still going on, and partly because of unavailable data due to censorship. This concerns to a great extent also people living outside the combat area, not at least Kurds in the northern parts of Iraq and the Shiite population in the south.

4.8.1 Military Deaths and Injuries During and After the War

In comparison with many military conflicts in the past, the Gulf War was one of the most intensive and devastating. The bombardment was very intensive. In just 43 days, over 84,000 tons of bombs were dropped over an area of about 4,000 square miles (Sadiq and McCain, 1993). Allied forces were expecting high casualties in the war, even up to 40,000 in some estimates. Instead allied forces suffered casualties of only 149 dead and another 513 wounded (Sadiq and McCain, 1993). Until October 1991 had 44 Americans been killed by anti-personnel mines and left ammunition. Moreover, thousands of allied soldiers were injured during the offensive. In the years following the war a number of soldiers have been killed in connection with mine clearance. The exact number is not known, but the figure is probably between 50 and 100. The total losses of Iraqi solders were much higher, but information on Iraqi casualties is very limited and at best speculative. The majority of the estimates reported more than 100,000 Iraqi personnel dead during 43 days of war (Sadiq and McCain, 1993). Nearly 25,000 of these were killed along the “road of death” (the road leading from Kuwait City to the Iraqi border), during a mass retreat. In comparison the number killed during the eight-year Iran-Iraq War is assumed to be approximately 100,000. Another 100,000 were wounded, the majority of whom later died due to lack of medical facilities and medicine.

4.8.2 Gulf War Syndrome (GWS)

During Operation Desert Storm, more than half a million US and coalition forces were exposed to the hash desert environment in the Persian Gulf. Although the troops might have been exposed to potentially toxic substances such as fumes and smoke from the burning oil wells, toxic paints, pesticides, and to certain extent dust from depleted uranium, it is unlikely that troops were exposed to chemical or biological weapons (Husain, 1995). However, Iraq had used nerve gas both in the war with Iran and against residents of Kurdish villages, and there were reasons to suspect biological or chemical weapons might be used again. For the prevention for such attacks, some 100,000 allied troops were vaccinated against anthrax and another 8,000 against botulism toxoid, two suspected biological agents (Enserink, 2001). In addition many soldiers took pyridostigmine bromide tablets, which were supposed to protect against a gas attack. All these factors, including the stress of exposure to traumatic wartime events, could have contributed to the symptom called Gulf War Syndrome (GWS). Even before they returned home, the first Gulf veterans had become ill. There are neither specific symptoms that identify GWS nor any overall specific pattern of diseases that the Gulf War veterans report. The most common symptoms seem to be fatigue, followed by depressed mood or anxiety, and then pain (Ferrari and Russell, 2001). Other symptoms reported are dizziness, forgetfulness, loss of concentration, headaches, muscle pain, skin rash, and respiratory symptoms. Some veterans have reported illnesses in their spouses and birth defects in children conceived after the conflict.

Still after more than 10 years, scientists are unable to explain what caused GWS. Large efforts have been spent on research and numerous research papers published. Since it is only veterans from U.S, United Kingdom and Canada that have experienced these symptoms, they cannot be explained as psychosomatic and/or stress-related. Several studies have suggested the GWS may have been caused by a combination of factors acting in a synergetic way. Such factors may include pesticides used in the military camps, the treatment with pyridostigmine bromide, the use of insect repellents, vaccinations, and exposure to depleted uranium (Landrigan, 1997). In 1996, the U.S Department of Defense reported that some Allied troops were potentially exposed to chemical warfare agents as the result of the detonation of Iraq munitions at Khamisiyah, northwest of Basra. Approximately 20,000 soldiers could have been exposed to these chemicals. However, the U.S Department of Defense claimed that the exposure levels were too low to cause symptoms, and studies have shown that soldiers outside of a 50 km of the Khamisiyah detonation site are not at increased risk (McCauley et al., 2002). In conclusion there is no scientific evidence that the troops served in the Gulf War have any unique pattern of illness, other than various symptoms of stress, which can be causally linked to their military service in the Gulf. Researchers have found that the health complaints of Gulf War veterans are similar to those of the general military population and are not consistent with the existence of a unique Gulf War syndrome (Doebbeling et al., 2000). Therefore several experts now claim that the substantial amount of analysis and data rather indicates that there is no such thing as the GWS. It is not known at this point whether parts of the Iraqi troops have been exposed to nerve agents and other chemicals.

4.8.3 Kuwaiti Civilian Deaths and Injuries During and After the War

There are a large number of evidence of the physical brutality against Kuwaitis as well as foreign guest workers during the occupation period. The Iraqi army was ordered to identify all Kuwaiti civilians as actual or potential opponents to the Iraqi regime. The assaults seemed to happen randomly and included killing and torture. The exact extent of Kuwaiti civilian killed by Iraqi soldiers is not known, but has been estimated to between 400 and 600 people. The total number of Kuwaitis that died as a result of the Iraqi occupation has been estimated at about 2,000 dead (see Table 18). This includes those who died because medicine was not available, hospitals were not functioning etc. Another consequence of the invasion was the displacement of a large number of Kuwaiti and non-Kuwaiti families. Having no previous experience with war, the population was caught unprepared by the rapid invasion. Many Kuwaitis, guest workers and expatriates were arrested and put in prisons in Kuwait or Iraq. The total number of Kuwaiti civilians put in prison was between 15,000 and 16,000. Most of them were released in connection to the allied invasion or shortly after, but 300 to 500 people are still missing and are still considered to be in Iraqi prisons or have been killed.

As mentioned above, several million mines were deployed by the Iraqi soldiers to slow the advancement of allied forces. After the war, Kuwait was left littered with these mines as well as live and spent ammunition and it was extremely dangerous to move around in large parts of the country. In the first period after the liberation (March to December 1991), the number of injuries due to mines and live ammunition in Kuwait was estimated to be 539 and 486 respectively (see Table 19). The figures are probably slightly higher as not all injuries were reported. Losses of limbs, fingers etc, as well as facial injuries with losses of eyes were reported to be common consequences of mine accidents after the war. After the occupation, 33 persons in 1991 and 24 persons in 1992 died due to land mines and ammunition accidents (Al-Hammadi et al., 1994). A landmine casualty database has been established by Kuwait Institute for Scientific Research, which shows there have been more than 1,500 civilian mine and ammunition victims in Kuwait since August 1990 (see Table 20).

Table 18: Number of deaths of Kuwaiti people during the period of occupation (Al-Hammadi and Al-Abdalrazaq, 1995)

Reason of death	Number of death
Injuries of war	465
Heart problems	492
Car accidents	147
Cancer	170
Renal failure	59
Lack of medication	596
Unknown	99
Total	2028

Table 19: Number of physical injuries that were recorded after liberation due to mines and ammunition according to age and sex. (Al-Hammadi and Al-Abdalrazaq, 1995)

Month and Year	March-December 1991	January-December 1992	January-December 1993	Total
Cause/ age				
Mines/ < 14 years	166	27	2	195
” / 14-40 years	323	138	80	541
” / > 40 years	50	0	17	67
Total	539	165	99	803
Ammunition/ < 14 years	78	2	1	81
” / 14-40 years	381	48	14	443
” / > 40 years	27	1	2	30
Total	486	51	17	584
Total	1025	216	116	1387

Table 20: Civilian mine and ammunition casualties, August 1990 to January 2001. (Source: Homepage for “International campaign to ban landmines” http://www.icbl.org/lm/2001/kuwait/#fn5190).

Hospital	Number of casualties
Amiri	536
Sabah	379
Mubarak	98
Adan	190
Al Razi	330
Total	1,533

Apart from the direct physical injuries, many of the civilians were mentally affected by the occupation and the following war. Over 50% of the population who were in Kuwait at the beginning of the invasion went into hiding for three days or more during the occupation (Al-Hammadi et al., 1994). A large portion of the population witnessed violence. Thousands of children were directly or indirectly affected by the violence. Most of the children were witnessing fighting, destruction of property, physical assault, and killing, and one third of the Kuwaiti children in a study made in Saudi Arabia have witnessed physical assault by family members or had they been physically assaulted themselves (Al-Eissa, 1995). Most frequently, these children were suffering from psychosomatic disorders, anxiety and depression signs, aggressive or regressive behavior, withdrawal from society, and emotionally instability. About 2.5 years after liberation 27% of the adult population was diagnosed to have a mental disorder, called Post-Traumatic Stress Disorder (PTSD) (Al-Hammadi et al., 1994). Younger adults showed a higher prevalence of PTSD, and the reason for this could be that they had been the more active group during the occupation, therefore having witnessed more of the stressful events. The prevalence of PTSD for children is however lower that for the adult sample (17%). Many of the civilians in Kuwait are still, more than 10 years after the war, suffering of mental diseases as a result of the war. The Center for Psychological and Mental Health in Kuwait City treated in 1997 1,200 patients with severe PTSD-symptom, and they estimated that 17% of the population had PTSD-symptom. Of the torture survivors had, six years after the war, 40% severe PTSD-symptom. Apart from obvious PTSD-symptom, it has been reported that violence, behavioral disturbance, psychosomatically problems, and drug abuse have increased in Kuwait after the war, especially among younger people. Kuwait was considered a relatively friendly and peaceful environment before the occupation, with low criminality and few violent crimes. After the war crime and violence has become more common and the use of weapons almost a part of the daily life. Reports also indicate that violence has become more common in schools. As mentioned before, it appears from many reports that people’s attitude to the society and life in general changed after the war. Many Kuwaitis complain about mental depression and insecurity.

4.8.4 Iraqi Civilian Deaths and Injuries During and After the War

It is generally accepted that an accurate account of Iraqi military causalities will never be known, but an assessment of the civilian casualties is extremely difficult to make. Between 2,500 to 3,000 civilians death were directly related to the allied bombardment. It was often mentioned during the war that many Iraqi targets were in populated areas. Many of the facilities that were bombed; ordnance factories, military facilities, and communication centers, were run partially or wholly by civilians. Even if the main target was the military infrastructure, civilian facilities were also hit, including residential buildings. Until March 1991 20 bombs dropped by the allied had destroyed approximately 9,000 homes. Parts of Basra, but also Baghdad, were completely ruined. However, the aftermath of the Gulf War presented Iraq with the most serious problems. The war and the following UN embargo depleted the stocks of expiable medicine. Additionally, the Allied bombardment knocked out many of electric, communication, and sanitation facilities, and destroyed much of Iraq's infrastructure. The situation in Iraqi hospital was at times said to be desperate. Many hundreds of thousands of people, including infants and children, may have died due to the lack of medicine, hospital supplies, and medical services. Many of those wounded in the war also died as the medical supplies were not available. Little objective information is available about the effect of the economic sanctions, war, and civilian uprisings on the health of civilians. An international team that visited Iraq in April 1991 reported epidemics of cholera, typhoid, and gastroenteritis and found that mortality rates had increased two to three times among children admitted to hospitals in Baghdad and Basra (The Harvard Study Team, 1991). Other studies provide strong evidence that the Gulf War and trade sanctions caused an increase in mortality among Iraqi children. More than 46,900 children under five years age died between January and August 1991 due to the war and its aftermath (Ascherio et al., 1992)

Iraq did not use chemical weapons during the Gulf War. However, the allied forces destroyed several facilities supposedly containing toxic chemicals during and after the war. No reliable information is available regarding the extent of damage to Iraq's chemical weapon plants and stockpiles and whether toxic chemicals were released as a result of bombing. Considering the extent of allied bombing, it may be suspected that damage to chemical weapon facilities and stockpiles might have been extensive. If released, it is not known whether the local population was contaminated and if so to what extent. Reports suggest that depleted uranium was the cause of congenital malformations, leukemia, and other undiagnosed diseases in Iraq after the war (UNICEF, 1998). Although studies of depleted uranium have been few, it have been proven that depleted uranium may be the cause of fatal illnesses including cancer and various stomach ailments showing up in Iraqi children. However, studies of the levels of depleted uranium in soil samples after the war in former Yugoslavia does not indicate and significant levels.

During April and May 1991, the Iraqi army forced 1,9 million Kurds, mostly women and children, to flee from northern Iraq to rather primitive camps in the border districts near Turkey and Iran. As a result of severe conditions before, during, and after the escape, at least 70,000 people mostly children died. The circumstances in the camps were at times very bad and in the month of April nearly 1,000 children died per day. Also in the south the Shiite population suffered from heavy repression. It has been estimated that about 100,000 people died in Kurdistan and southern Iraq in the civil unrest immediately after the war. As a result the allied proclaimed several “safe havens” in Kurdistan in the end of 1991, in attempts to improve the condition in the camps and to prevent that the Iraqi military aggravating the situation further. The population inside these “safe havens” received a good protection against the Iraqi army, but needed extensive humanitarian aid, mainly supplied from the Red Cross. While the security situation for the Kurd’s in north gradually improved, the Shiites in southern parts of Iraq suffered from repression by the Iraqi army and tried to start a civil war. When Saddam Hussein’s troops, mainly the Sunni-dominated Republican Guards, crushed this revolt, large numbers of people fled to the marshes. The Iraqi army followed and extensive military operations started to conquer the rebellion. One method of preventing the Shiites from seeking protection in the marsh-land was to drain the area. After about 10 years about 90% of the marshland of the delta of the Euphrates and Tigris have been drained. In addition the infrastructure of the southern cities was destroyed during the attempts of the army to crush the Shiite uprising. Thirty percent of the buildings in the city of Basra, which was the center of the revolt, were completely destroyed. The number of casualties is not known, but has been estimated to close to 30,000 people.

The economic sanctions against Iraq have, as mentioned above, had a devastating effect on the majority of Iraqi people, especially children and the elderly. Concerned about the suffering of the civilian population and in an attempt to mitigate the impact of the continuing sanctions, the UN Security Council adopted resolution 986 in April 1995. This provided an “oil for food” formula designed as a temporary measure to provide for the humanitarian needs of the Iraqi people. The resolution went into effect on December 10, 1996, but the plan did not fully protect the Iraqi civilians from the effects of the sanctions and the levels of malnutrition and disease is still clearly elevated compared to the situation before the war. Nutrition surveys carried out by UNICEF over the last four years show that since the introduction of the “Oil for Food Programme” in 1996 the nutritional status of children has stabilized, but has not improved significantly (UNICEF, 2002). UNICEF reported in 1998 an increase of mortality of children in Iraq under five years of age, which is an excess of some 40,000 deaths yearly compared with 1998. The increase is mainly due to diarrhea, pneumonia, and malnutrition. In the population over 5, the increase, an excess of some 50,000 deaths yearly, is associated with heart disease, diabetes, cancer, liver or kidney diseases. This increase in mortality among infants and children has been associated with increase illness in combination with inadequate health care, worsening living standards, and compromised water and sanitation (UNICEF, 1998).

The allied forces reported at the end of January 1991 that 31 factories for production of biological, chemical and nuclear weapons have been destroyed. It was known that Iraq, at the time for the invasion, had the capacity to produce 8 tons of the nerve gas tabun and 60 tons mustard gas per month. Moreover, Iraq possessed over 4,000 tons sarin, lewisite and cyanogenchloride, as well as 2,500 liters of aflatoxine, 8,500 liters of anthrax, and 19,000 liters of botulinium. Whether these chemicals were destroyed by the bombings and reached the environment is not known. In April 1991, the United Nations established a Special Commission (UNSCOM 1998) and charged it with the task of destroying, removing, or rendering harmless all chemical and biological weapons and all stocks of agents and all related subsystems and components and all research, development, support and manufacturing facilities. By the time UNSCOM left Iraq in December 1998, it had eliminated a large portion of Iraq's chemical weapon potential. UNSCOM had overseen the destruction or incapacitation of more than 38,000 filled or unfilled chemical munitions, over 600 tons of bulk chemical agents, more than 3,000 tons of precursor chemicals, some 420 pieces of key production equipment, and almost 100 pieces of related analytical equipment (UNSCOM homepage, 2002). Notwithstanding these achievements, there are still important uncertainties regarding Iraq's holdings of chemical weapons, their precursors, and munitions. In 1999 the United Nations Monitoring, Verification and Inspection Commission (UNMOVIC 1999) was created through the adoption of Security Council resolution 1284. UNMOVIC was to replace UNSCOM and continue with the latter's mandate to disarm Iraq of its weapons of mass destruction (see http://www.un.org/Depts/unmovic/, http://www.un.org/Depts/unscom/Achievements/achievements.html).

4.8.5 Health Impact of Air Pollutants

The Kuwait oil fires emitted pollutants that potentially could affect the health and well-being of the people in the region. Most of the substances emitted from the burning wells can potentially cause adverse effects, which vary according to concentration and duration of exposure. During the period of the Kuwaiti oil fires it was difficult to make a precise estimate of health risks because of lack of continuous air pollution monitoring data. At the initial stage of the fires, there was great concern about acute health effects on the population and troops in the region. However, after air pollution monitoring began, it was noticed that as a result of the unexpectedly high combustion efficiency, the concentrations of pollutants were much lower than was expected.

Ambient concentrations of sulfur dioxide (SO_2) were found to be below air quality standards throughout the Gulf region. However, high concentrations were recorded near the burning oil wells and therefore firefighters could have been exposed to elevated SO_2 levels. The Kuwaiti oil fires could potentially produce very large quantities of SO_2 but fortunately most of the SO_2 was oxidized immediately to sulfate and then to calcium sulfate. Concentrations of nitrogen oxides (NO_x) and carbon monoxide (CO) in the smoke plume and on the ground were mostly below the air quality guidelines and certainly below the toxicity limit necessary to induce adverse health effects. At the beginning of the event, the fire extinguishing teams were worried that, due to a high concentration of sulfur in the crude oil and its incomplete burning, the concentration of H_2S might be at a dangerous level. However, even at an early stage of the Kuwaiti oil fires, the potential threat from H_2S was discounted as the levels were found to be low or even below the detection limits.

The concentrations of gaseous pollutants in Kuwait before the war and during the acute phase of the burning oil fires are shown in Table 21. Concentrations of lead, cadmium, and cobalt in inhalable particles were found to be higher than their assumed safe limits, whereas nickel, vanadium, and copper were within safe limits. Organic pollutants, like aromatic hydrocarbons (PAH), aliphatic hydrocarbons, and volatile organics, have several sources. The most important during the Gulf crisis were emissions from the oil fires, evaporation from oil lakes, trenches filled with oil, the oil spill, combustion products from military hardware, and fallout from explosives. The mean concentrations of volatile organics measured in Kuwait during the fires were typical of those found in industrial/urban situations with large numbers of vehicles and combustion from power plants, industry etc. The highest levels were found, as expected, in and around the burning oil fields. The PAH concentrations found in the Gulf region were comparable to those found in urban areas in several parts of the world. (Husain, 1993, Husain, 1998).

Table 21: Concentration of gaseous pollutants in Kuwait, 1991 in comparison to 1990 mean values in Kuwait (Husain, 1998).

Stations	SO_2 (µg/m^3)	NO (µg/m^3)	NO_x (µg/m^3)	Non-methane hydrocarbons (mg/m^3)	Methane (mg/m^3)
Mansoria 1990	4.69	30.00	77.60	0.29	1.15
Mansoria 1991	5.99	16.40	43.20	1.33	1.74
Increase (as %)	+ 28%	- 45%	- 44%	+ 352%	+ 50%
Rega 1990	3.65	35.20	83.60	0.27	1.13
Rega 1991	7.82	120.4	161.6	0.41	1.09
Increase (as %)	+ 114%	+ 242%	+ 93%	+ 48%	- 4%
Average increase	+ 71%	+ 98%	+ 25%	+ 200%	+ 23%

There is a lot of scientific evidence linking air pollution levels with acute respiratory illness. A survey conducted in Kuwait clinics and emergency rooms during the oil fires showed an increase in upper respiratory irritation, chronic bronchitis, and emphysema (Osman, 1997). However, studies on the onset of asthma among the Kuwaiti population during and after the fires have not shown any significant rise of asthma cases after the war (Al-Khalaf, 1998). It should be mentioned that the data, which were obtained from the Ministry of Health, may be underestimated and therefore inaccurate. Many mysteries still remain unresolved about the smoke from the oil well fires. While high levels of sulfur dioxide were measured in the well fields, the ground-level concentrations of sulfur dioxide in the major population centers were less than the ambient standards of the U.S Environmental Protection Agency's air pollution index (Al-Ajmi and Marmoush, 1996). Measurements in Kuwaiti houses in 1993 showed that the concentration of volatile organic compounds (VOC) was surprisingly low and that they are below the concentrations set by the American Hygienists Association (Bouhamra, 1995). Limited available data suggest that there may be some chronic health effects, especially from metals and organic chemicals, which could be associated with the Gulf War. The most probable indications may be higher blood pressure, increased respiratory tract complains, enhanced incidence of cancer, and cardiovascular disorders. No increase in cancer rates has been observed in Kuwait after the Gulf War. Studies on post-war cancer rates in different gender and age groups are made during a 20-years period, since many cancer outcomes have long latency periods.

References

Abu Zinada A.A. and Belcher N. 1992. Report on the effects of the 1991 oil spill on the wildlife of the Arabian Gulf and the efforts by the National Commission of Wildlife Conservation and Development. Fourth General Conference, Third World Academy of Sciences, Kuwait, November 23-26 1992.

Ahmed, M.H., El-Raey, M., Nasr, S.M. and Frihy, O.E. 1998. "Socioeconomic impact of pollution on ecosystem of the Arabian Gulf." Environment International 24(1-2):229-237

Al-Ajmi, D.N. and Marmoush, Y.R. 1996. "Ground level concentration of sulphur dioxide at Kuwait's major population centers during the oil-field fires." Environment International 22(3):279-287

Al-Awadhi, N., Balba, M.T., Puskas, K., Al-Daher, R., Tsuji, H., Chino, H., Tsuji,K., Iwabuchi, M., Kumamoto, S. 1995. "Remediation and rehabilitation of soil contaminated lake beds." Journal of Arid Land Studies 5: 195-198

Al-Awadi, E., Mukhopadhyay, A. and Quinn, M. F. 2001. "A preliminary investigation of the hydrocarbon content of groundwater of Kuwait" Environmental Geology 41:330-340

Al-Besharah, J. 1991. "The Kuwaiti oil fires and oil lakes – facts and numbers." In: Environmental and Health Impact of the Kuwaiti Oil Fires. Proc. Of an International Symp. Held at the University of Birmingham, 17th October.

Al-Dabi, H., Koch, M., Al-Sarawi, M. and El-Baz, F. 1997. "Evolution of sand dune patterns in space and time in Northern Kuwait using Landsat TM Images" Journal of Arid Environments, Volume 36, Issue 1, May 1997, Pages 15-24

Al-Eissa, Y.A. 1995. "The impact of the gulf armed conflict on the health and behaviour of kuwaiti children." Social Science & Medicine. 41(7):1033-1037

Al-Hammadi, A., Staehr, A., Behbehani, J., Staerh, M., Aref, M., Al-Turkait, F. and Al-Asfour, A. 1994. The traumatic events and mental health consequences resulting from the Iraqi invasion and occupation of Kuwait. Al-Riggae Specialised Centre. Kuwait.

Al-Hammadi, A.M. and Al-Abdalrazaq, A. 1995. Atlas of Iraq war crimes in the state of Kuwait. Kuwait Ministry of Information. Second Print.

Al-Hinai K.G., Khan A.A., Dabbagh A.E. and Bader T.A. 1993. " Analysis of Landsat Tematic Mapper Data for mapping oil slick concentrations – Arabian Gulf oil spill 1991". The Arabian Journal for Science and Engineering, Vol 18(2): 85-93.

Al-Khalaf, B. 1998. "Pilot study: the onset of asthma among the Kuwaiti population during the burning of oil wells after the Gulf War." Environment International 24(1-2):221-225

Al-Merghani M., Miller J.D., Al-Mansi A. Khushaim O. and Pilcher N.J. 1996. "The marine turtles in the Arabian Gulf. NCWCD studies 1991-1994." In: Krupp F., A.H. Abuzinada and I.A. Nader (eds). A Marine Wildlife Sanctuary for the Arabian Gulf. Environmental Research and Conservation Following the 1991 Gulf War Oil Spill. National Commission for Wildlife Conservation and Development, Riyadh.

Al-Rabeh, A.H., Gunay, N., Cekirge, H.M., 1992. “Modeling the fate and transport of Al-Ahmadi oil spill.” Water, Air, and Soil Pollution 63.

Al-Sarawi, M., Massoud, M.S. and Al-Abdali, F. 1998. “Preliminary assessment of oil contamination levels in soils contaminated with oil lakes in the greater Burgan oil field, Kuwait” Water, Air, and Soil Pollution 106:493-504

Al-Sulaimi, J. and Mukhopadhyay, A. 2000. “An overview of the surface and near-surface geology, geomorphology and natural resources in Kuwait.” Earth-Science Reviews 50:227-267

Al-Yahya, M.A. 1993. Kuwait: Fall and Rebirth. Kegan Paul International London and New York

Ascherio, A., Chase, R., Cote, T., Dehaes, G., Hoskins, E., Laaouej, J., Passey, M., Qaderi, S., Shuqaidef, S., Smith, M.C. and Zaidi, S. 1992. “Effect of the Gulf War on the infant and child mortality in Iraq.” The New England Journal of Medicine 327(13):931-936

Bakan, S., Chlond, A., Cubasch, U., feichter, J., Graf, H., Grassel, H., Hasselman, K., Kirchner, I., Latif, M., Roeckner, E., Sausen, R., Schlese, U., Schriever, D., Schult, I., Schumann, U., Sielmann, F. and Welke, W. 1991. “Climate response to smoke from the burning oil wells in Kuwait.” Nature 351:367-371.

Balba, M.T., R. Al-Daher, N. Al-Awadhi, H. Chino and H. Tsuji.1998. Bioremediation of Oil- Contaminated Desert Soil: The Kuwaiti Experience. Environment International 24(1/2):163- 173.

Barnaby, F. 1991. “The environmental impact of the Gulf War.” Ecologist 21:166-172.

Barth, H.J. 2002. Die Küstenökosysteme am Arabischen Golf 10 Jahre nach dem Golfkrieg. *Geographische Rundschau* 54(12): 36-42.

Biswas, A.K. 2002. “Scientific assessment of the long-term environmental consequences of war.” In: Austin, J.E. and Bruch, C.E. (eds). The environmental consequences of war: Legal, economic, and scientific perspectives. Cambridge University Press.

Böer, B. 1996. “Trial planting of mangroves (Avicennia marina) and salt-marsh plants (Salicornia europaea) in oiö-impacted soil in the Jubail area, Saudi Arabia.” In: Krupp F., A.H. Abuzinada and I.A. Nader (eds). A Marine Wildlife Sanctuary for the Arabian Gulf. Environmental Research and Conservation Following the 1991 Gulf War Oil Spill. National Commission for Wildlife Conservation and Development, Riyadh.

Bouhamra, W.S. 1995. “Estimation of volatile organic compounds in Kuwaiti houses after the Gulf War.” Environmental Pollution 90(1):121-125

Bou-Rabee, F. 1995. “Estimating the concentration of uranium in some environmental samples in Kuwait after the 1991 Gulf War” Applied Radiation and Isotopes 46:4:217-220

Bou-Rabee, F., Bakir, Y. and Bem, H. 1995. “Contribution of uranium to gross alpha radioactivity in some environmental samples in Kuwait” Environmental International 21 No.3:293-298

BP, 2002. “Statistical Review of World Energy 2002.” Available at: http://www.bp.com

Brauer, J. 2000. “The effect of war on the natural environment.” Paper for "Arms, Conflict, Security and Development Conference, Middlesex University, London. Available at: http://www.aug.edu/~sbajmb/files.htm

Browning K.A., Allen R.J., Ballard S.P., Barnes R.T.H., Bennetts D.A., Maryon R.H., Mason P.J., McKenna D., Mitchell J.F.B., Senior C.A., Slingo A., and Smith F.B. 1991. Environmental effects from burning oil wells in Kuwait. Nature 351, 363-367.

Bruch, C. Austin, J. and Parker, E. 1998. “Addressing environmental consequences of war.” Background paper for the First International Conference on Addressing Environmental Consequences of War. Environmental Law Institute, Research Report, Washington.

Bu-Olayan, A.H. and Subrahmanyam, M.N.V. 1996. “Trace metals in fish from the Kuwaiti coast using the microwave acid digestion technique” Environmental International 22(6):753-758

Bu-Olayan, A.H. and Subrahmanyam, M.N.V. 1997. Accumulation of copper, nickel, lead and zinc by snail, Lunella coronatus and pearl oyster, Pinctada radiate from the Kuwait coast before and after the gulf war oil spill” The Science of the Total Environment 197:161-165

CIA, 2002. “The World Factbook 2002.” Central Intelligence Agency, United States. Available at: http://www.odci.gov/cia/publications/factbook/index.html

Dickie, M. and Gerking, S. 2002. “Valuing public health damages arising from war.” In: Austin, J.E. and Bruch, C.E. (eds). The environmental consequences of war: Legal, economic, and scientific perspectives. Cambridge University Press.

Doebbeling, B.N., Clarke, W.R., Watson, D.L., Torner, J.C., Woolson, R.F., Voelker, M.D., Barrett, D.H. and Schwartz, D.A. 2000. “Is there a Gulf War syndrome? Evidence from a large population-based survey of veterans and nondeployed controls.” American Journal of Medicine, 108(9):695-704

Downing N. and Roberts C. 1993. “Has the Gulf war affected coral reefs of the northwestern Gulf?” Marine Pollution Bulletin, Vol. 27, 149-156.

EIA, 2002. “Kuwait Country Analysis Brief.” Official Energy Statistics from the U.S. Government, Energy Information Administration, August 2002 http://www.eia.doe.gov/emeu/cabs/kuwait.html

El-Baz, F. 1992. ”The war for oil: Effects on land, air and sea” Geotime:12-15

El-Nemr, I., Radwan, S., and Sorkhoh, N. 1995. “Oil biodegradation around roots.” Nature. 376: 302

Enserink, M. 2001. “Gulf War Illness: the battle continues.” Science 291:812-817

EPC, 1991. “State of the Environment Report. A Case Study of the Crimes Against the Environment. Environmental Protection Council, Kuwait.

Evans M.I. and Keijl G.O. 1993. The impact of the Gulf War oil spills on the wader populations of the Saudi Arabian Gulf coast. Sandgrouse 15 (Parts 1 & 2), 56-84.

Ferek, R.J., P.V. Hobbs, J.A. Herring and K.K. Laursen. 1992. "Chemical Composition of Emissions from the Kuwait Oil Fire" Journal of Geophysical Research, Vol. 97

Ferrari, R. and Russell, A.S. 2001. “The problem of Gulf War syndrome.” Medical Hypotheses 56(6):697-701

Fowler, S.W., Readman, J.W., Oregioni, B., Villeneuve, J.P. and McKay, K. 1993. “Petroleum hydrocarbons and trace metals in nearshore gulf sediment and biota before and after the 1991 war: An assessment of spatial and temporal trends” Marine Pollution Bulletin 27:171-182

Gleick, P.H. 1994. "Water, war, and peace in the Middle East." Environment. 36(3)

Green Cross International, 1998. An environmental assessment of Kuwait seven years after the Gulf War. Green Cross International Final Report, December 1998.

Gundlach E.R., McCain J.C. and Fadlallah Y.H. 1993. “Distribution of oil along the Saudi Arabian coastline (May/June 1991) as a result of the Gulf war oil spills.” Marine Pollution Bulletin, Vol. 27, 93-96.

Hadi, K. 1993. “The impacts of the oil lakes on the fresh groundwater lenses in Kuwait”. Kuwait Institute for Scientific Research

Harbard C. and Wolstencroft J. 1992. The ICBP/NCWCD waterbird survey of the Gulf coast of Saudi Arabia during November-December 1991. International Council for Bird Preservation

Hayes M.O., Michel J., Montello T.M., Aurand D.V., Al-Mansi A.M., Al-Moamen A.H., Sauer T.C. and Thayer G.W. 1993. “Distribution and weathering of shoreline oil one year after the Gulf war oil spill” Marine Pollution Bulletin, Vol. 27:135-142.

Hobbs, P.V. and Radke, L.F. 1992. “Airborne studies of the smoke from the Kuwaiti oil fields fires” Science 256:987-990

Husain, T. 1995. Kuwaiti oil fires: Regional environment perspectives. 1st ed. Oxford, UK:BPC Wheatons Ltd

Husain, T. 1998. “Terrestrial and atmospheric environment during and after the Gulf War” Environmental International 24:189.196

ITOPF. 2002. “Accidental tanker oil spill statistics” International Tanker Owner Pollution Federation Ltd. 2002. Available at: http://www.itopf.com

ITOPF 2003. Ocean Orbit. March 2003.

Jones, D.A. and Richmond M. 1992. “Intertidal and sub-tidal marine habitat surveys.” In: Final Report of Phase 1, Establishment of a Marine Habitat and Wildlife Sanctuary for the Gulf Region. National Commission for Wildlife Conservation and Development, Riyad, and European Community Commission.

Jones, D.A., Plaza, J., Watt, I. And Al-Sanei, M. 1996. “Long-term (1991-1995) monitoring of the intertidal biota of Saudi Arabia after the 1991 Gulf War oil spill” Marine Pollution Bulletin 36(6):472-489.

Kaplan R.D. 1996. The ends of the earth. A journey to the frontiers of anarchy. First Vintage Departure Edition, Random House, New York. 476 pp.

Khan, N.Y. 2002. ”Physical and human geography.” In: Khan, N.Y., Munawar, M. and Price, A.R.G. (eds.) 2002. The Gulf Ecosystem – Health and Sustainability. Backhuys Publishers, Leiden, The Neiderlands.

Khordagui, H., Al-Ajimi, D. 1993. ”Environmental impact of the Gulf War: an integrated preliminary assessment. Environmental Management 17:557-562

Klare, M.T. 2001. Resource Wars: The new landscape of global conflict. Metropolitan Books, New York.

Krupp F. and Jones D. 1993. The creation of a marine sanctuary after the Gulf War oil spill. Marine Pollution Bulletin 27, 315-323.

Krupp, F. and Khushaim, O. 1996. “The Jubail Marine Wildlife Sanctuary” In: Krupp F., Abuzinada A.H. and Nader I.A. (eds). 1996. A marine wildlife sanctuary for the Arabian Gulf. Environmental research and conservation following the 1991 Gulf war oil spill. National Commission for Wildlife Conservation and Development, Riyad.

Kwarteng, A.Y and Bader, T. 1991. “Monitoring the Kuwaiti oil fields using satellite data. Proc. 1st Bahrain International Conference on Environment, 24-26 February.

Kwarteng, A.Y. 1998. “Multitemporal remote sensing data analysis of Kuwait’s oil lakes” Environmental International 1-2:121-137

Kwarteng, A.Y. 1999. ”Remote sensing assessment of oil lake and oil-polluted surfaces at the Greater Burgan oil filed, Kuwait.” International Journal of Applied Earth Observation and Geoinformation 1:36-47.

Landrigan, P.J. 1997. Illness in Gulf War veterans.” Journal of the American Medical Association 277:259-261

Le Billon, P. 2001. “The political ecology of war: natural resources and armed conflicts.” Political Geography 20:561-584

Lindén, O. and Husain, T. 2002. “Impact of wars; the Gulf War 1990-1991.” In: Khan, N.Y., Munawar, M. and Price, A.R.G. (eds). 2002. The Gulf Ecosystem: Health and Sustainability. Backhuys Publishers, Leiden, The Netherlands.

Literathy, P., Khan, N.Y. and Lindén, O. 2002. “Oil and petroleum industry.” In: Khan, N.Y., Munawar, M. and Price, A.R.G. (eds). 2002. The Gulf Ecosystem: Health and Sustainability. Backhuys Publishers, Leiden, The Netherlands.

Loretz, J. 1992 “The animal victims of the Gulf War” The PSR Quarterly:221-225

Massoud, M.S., Al-Sarawi, M. and Wahba, S.A. 2000. “Variations in the chemical properties of soils contaminated with oil lakes in the greater Burgan oil fields, Kuwait” Water, Air and Soil Pollution 118:281-291

Mathews, C.P., Kedidi, S., Fita, N.I., Al-Yahya, A. and Al-Rasheed, K. 1993. “Preliminary assessment of the effects of the 1991 Gulf War on Saudi Arabian prawn stocks” Marine Pollution Bulletin 27:251-271

McCauley, L.A., Lasarev, M., Sticker, D., Rischitelli, D.G. and Spencer, P.S. 2002. ”Illness experience of Gulf War veterans possibly exposed to chemical warfare agents.” American Journal of Preventive Medicine 23(3):200-206

McKinnon, M. and Vine, P. 1991. Tides of war. Immel Publishing Ltd.

McNeely, J.A. 2000. “War and biodiversity: an assessment of impacts” In: Austin, J.E. and Bruch, C.E. (eds). The environmental consequences of war: Legal, economic, and scientific perspectives. Cambridge University Press.

Meakins, R.H. and S. Y. Al-Mohanna, 2000. Sea Turtles in Kuwait after the Gulf War. Marine Turtle Newsletter 88, 7-8

Miller J.D. 1989. Marine turtles. An assessment of the conservation status of marine turtles in the Kingdom of Saudi Arabia. Volume 1. MEPA Coastal and Marine Management Series Technical Report No. 9.

Miller J.D., Limpus C.J. and Ross J.P. 1989. Marine turtles. Recommendations for the conservation of marine turtles in Saudi Arabia. Volume 2. MEPA Coastal and Marine Management Series Technical Report No. 9.

Misak, R., Omar, S. A. S. and Shahid, S. A. 2001. ”Oil trenches a continuing threat to the terrestrial environment of Kuwait” Contaminated soil, sediment and water. August 2001

Myers, N. 1993. Ultimate Security: the environmental basis of political stability. W.W. Norton & Company, London. 308 pp.

Myers N. and Kent J. 1995. Environmental Exodus: An emergent crisis in the global arena. The Climate Institute, Washington DC. 214 pp.

Obuekwe, C.O. and Al-Zarban, S.S. 1998. “Bioremediation of crude oil pollution in the Kuwaiti desert: the role of adherent microorganisms” Environmental International 24(8):823-834

Omar, S.A.S, Briskey, E., Misak, R and Asem, A.A.S.O. 2000. “ The Gulf War impact on the terrestrial environment of Kuwait: an overview.” In: Austin, J.E. and Bruch, C.E. (eds). The environmental consequences of war: Legal, economic, and scientific perspectives. Cambridge University Press.

Osman, Y. 1997. “Environmental syrvey conducted in the Gulf region following the Gulf War to identify possible neurobehavioral consequences.” Environmental Research 73(1-2):207-210

Pilcher, N. 1992. “The nesting habits of green turtle Chelonia myads and the hawksbill turtle Eretmochelys imbricate in the Arabian Gulf during 1991.” National Commission for Wildlife Conservation and Development. Report.

Preen, A. 1991 “Report of the die-off of marine mammals associated with the Gulf War oil spill.” Report for National Commission for Wildlife Conservation and Development.

Prena J. 1996. “The status of the intertidal soft-bottom macrofauna six months after the Gulf war oil spill”. In: Krupp F., Abuzinada A.H. and Nader I.A. (eds). 1996. A marine wildlife sanctuary for the Arabian Gulf. Environmental research and conservation following the 1991 Gulf war oil spill. National Commission for Wildlife Conservation and Development, Riyad.

Price, A.R.G., Mathews, C.P., Ingle, R.W. and Al-Rasheed K. 1993. "Abundance of Zooplankton and penaeid shrimp larvae in the western Gulf: Analysis of pre-war (1991) and post-war data" Marine Pollution Bulletin 27:273-278

Price, A.R.G., Sheppard, C.R.C. and Roberts, C.M. 1993. "The Gulf: Its biological setting." Marine Pollution Bulletin 27:9-15

Roberts, A. 2002. "The law of war and environmental damage." In: Austin, J.E. and Bruch, C.E. (eds). The environmental consequences of war: Legal, economic, and scientific perspectives. Cambridge University Press.

Sadiq M. and McCain J. 1993. The Gulf War aftermath. An environmental tragedy. Kluwer Academic Publisheries. 298 pp.

Sadiq M., Saeed T. and Fowler S. 2002. Seafood contamination. *pp 327-351 in* The Gulf Ecosystem: Health and Sustainability. Eds: N.Y. Khan, M. Munawar & A. Price. Backhuys Publishers.

Salam, A.L.A., 1996. "The oil lakes environment disaster" In: Al-Awadi, A., Balba, M.T. and Kamizawa, C. (eds.) Proc. Of the Symposium on Restoration and Rehabilitation of the Desert Environment. Elsevier Amsterdam.

Sandia, 1991. "Operation quick response predicting environmental effects of oil sabotage." Energy and Environment, July, Sandia National Laboratories.

Sheppard, C.R.C. 1993. "Physical environment of the Gulf relevant to marine pollution: An overview." Marine Pollution Bulletin 27:3-8.

Sheppard C., Price A., and Roberts C. 1992. Marine ecology of the Arabian Gulf. Patterns and processes in extreme tropical environments. Academic Press. London.

Shouse, B. 2001. The Gulf War's Aftermath, Kuwait Unveils Plan to Treat Festering Desert Wound. Science magazine, 24 August 2001, vol 293, page 1410.

Small, R.D. 1991. "Environmental Impact of Fires in Kuwait." Nature, 350:11-12

Suthers, J.R. 1991. "Air and water pollution in Jubail." P.32-39. In:A.K.S Al-Shatti, J.M. Harrington (eds.), Proceedings of an International Symposium on the Environmental and Health impact of the Kuwaiti Oil Fires. 1991 Oct. University of Birmingham

Symens P. and Alsuhaibany A.H. 1996. "Status of the breeding populations of terns (Sternidae) along the eastern coast of Saudi Arabia following the 1991 Gulf War." In Krupp F., A.H. Abuzinada and I.A. Nader (eds). A Marine Wildlife Sanctuary for the Arabian Gulf. Environmental Research and Conservation Following the 1991 Gulf War Oil Spill. National Commission for Wildlife Conservation and Development, Riyadh.

Tawfiq N.I. 1991. Response by Saudi Arabia to the Environmental Crisis caused by the Gulf war. Proceedings from the International Symposium on the Environmental and Health Impact of the Kuwait Oil Fires. The University of Birmingham, October 1991.

Tawfiq N.I. and Olsen D.A. 1993. ”Saudi Arabia’s response to the 1991 Gulf oil spill.” Marine Pollution Bulletin, Vol. 27, pp 333-345.

The Harvard Study Team, 1991. “The effect of the Gulf crisis on the children of Iraq.” The New England Journal of Medicine 325(13):

Turco, R.P., Toon, O.B., Ackerman, T.P., Pollack, J.B. and Sagan, C. 1990. “Climate and smoke: an appraisal of nuclear winter.” Science 247:166-174

UNEP, 1999. “Overview on land-based sources and activities affecting the marine environment in the ROPME sea area.” UNEP Regional Seas Reports and Studies No. 168.

UNEP, 2002. “UNEP And The United Nations Compensation Commission (UNCC) sign cooperation deal in the Persian Gulf Region.“ UNEP Information Note 2002:24. Available at: http://www.unep.org

UNESCO-WWAP, 2003. United Nations World Water Development Report, Water for People, Water for Life. UNESCO/Berghahn Books.

UNICEF, 1998. “Situation analysis of children and women in Iraq.” UNICEF/Iraq. 30 April 1998. Available at: http://www.childinfo.org/Other/Iraq_sa.pdf

UNICEF, 2002. Press release: Malnutrition down by half among Iraqi children. Retrieved Feb. 2003 from: http://www.unicef.org/media/media_19237.html.

UNMOVIC, 1999. United Nations Security Council 1999. Resolution 1284 of 17 December 1999.

UNSCOM, 1998. UNSCOM main achievements. Retrieved Jan 2003 from: http://www.un.org/Depts/unscom/Achievements/achievements.html

Watt I., Woodhouse T. and Jones D. 1993. “Intertidal clean-up activities and natural regeneration on the Gulf coast of Saudi Arabia from 1991 to 1992 after the 1991 Gulf oil spill.” Marine Pollution Bulletin, Vol. 27, pp 325-331.

Vogt, I. 1995. “Coral reefs in Saudi Arabia: 3.5 years after the 1991 Gulf War oil spill” Coral Reef 14:271-273

Vöneky, S. 2002. “Peacetime environmental law as a basis of state responsibility.” In: Austin, J.E. and Bruch, C.E. (eds). The environmental consequences of war: Legal, economic, and scientific perspectives. Cambridge University Press.

World Oil, 1991. Kuwait: the mother of all blowouts. World Oil:38-48

Zwarts L., Felemban H., and Price A. 1991. “Wader counts along the Saudi Arabian Gulf coast suggest that the Gulf harbours millions of waders.” Wader Study Group Bull. 63, 25-32.