Modelling of Coral Reefs Damage Assessment in Egypt

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Abstract – *Coral reefs are the most biological systems productive and versatile on the surface of the planet earth, which is a source with economic and social returns great for the country that God-given this natural wealth either through tourism activity or fishing with protecting the coastline from Sacrifice factors and thus protects all its coastal facilities. Egypt is home to some of the most spectacular coral reefs and associated marine life in the world. Egypt has enacted laws and takes effective measures for the protection and management of coral reefs and associated ecosystems in the Red Sea and its Gulf to characterize these areas of the richness and diversity of coral reef environment is scarce to be repeated elsewhere in the world. Coastal tourism is the largest sub-sector within the Egyptian tourism market. While coastal tourism depends largely on intact reefs, it is also the single most important cause of reef degradation in Egypt. Over the last two decades live coral cover has declined in Egypt. Egyptian Environmental Affairs Agency (EEAA) implements its own methodology to estimate the coral reefs impacts as a result of the destruction of coral reefs due to ship aground or anchorage. Referring to the EEAA approaches applied in Egypt, this paper focuses on and presents the modelling of the destruction of coral reefs due to the collision and the ship ground damage assessment in case of oil spills in Egyptian coastal water.*

Keywords*: Coral reefs, Economic, Tourism, Red sea, Damage, Assessment, Modeling and Oil spills.*

Nomenclature

EEAA: Egyptian Environmental Affairs Agency.
GIS: Geographic Information System
HEPCA: Hurghada Environmental Protection and Conservation Association
OSDAM: OIL SPILL DAMAGE ASSESSMENT MODEL
NOAA: National Oceanic and Atmospheric Administration
SST: Sea Surface Temperature

1. Introduction

The Red Sea is part of a major world shipping route which currently carries around 7 percent of the global seaborne trade. Much of the world's crude and refined oil cargoes pass through the Red Sea and Gulf of Aden. About 20,000 ships pass through the Strait of Bab al-Mandab each year and an estimated 25,000 to 30,000 ships transit the Red Sea annually. Apart from ship-related pollution risks (e.g. discharges of garbage and oily wastes; bunkering activities), accidents involving tankers together with discharges from unloading operations constitute a serious pollution risk (1).

Coral reefs in the Red Sea region are among the most spectacular in the world, it is the main attraction of tourism in Egypt. The rise of sea level will limit the light that reaches deep lying coral reefs which will no longer be capable of sustaining growth. Again the direct interrelationship of global warming, increase of ocean salinity and biodiversity of coral reef and marine life are well recognized in the coastal zone. Its implication on tourism and national income may be severe. The loss of biodiversity of medicinal plants, marine life and on land fauna and flora in coastal zone is also an important factor (4). Coral reefs are important because they bring in billions of dollars to our economy through tourism, protect coastal homes from storms, provide promising medical treatments, and provide a home for millions of aquatic species (13). Corals require a range of physical conditions for healthy growth and reproduction, all of which can be influenced by human activities. Physical destruction, changes in water quality—such as raised nutrient levels, changes in salinity and temperature, high levels of sedimentation and changes in water currents, can all damage coral reefs. Recovery, through new growth and larval settlement, requires a considerable amount of time and freedom from chronic stress (18).

Coral reefs are among the most biologically diverse ecosystems. They are important producers of nutrients and thus play a significant role for many marine species. While coral reefs have adapted to numerous natural impacts over thousands of years, the human impact is actually a greater threat, against which such a vulnerable ecosystem can hardly compensate (2). These reefs contribute a variety of valuable benefits to local communities and to the gross national product of countries in whose waters they lie. These benefits include commercial, artisanal and ornamental fisheries; bio-prospecting for new pharmaceuticals; mining; revenue from tourists keen to observe their natural beauty; and shoreline protection (17).

The coastal zones of Egypt host a major part of the industrial activities, including petroleum, chemicals and touristic distributed among a large number of highly populated economic centers such as Alexandria, Rosetta, Damietta, Port Said, Suez, Hurghada, and Sharm El-Sheikh (4). Many areas along the Egyptian coasts are at risk from natural impacts created by geological and meteorological disturbances of sea surface and man-made impacts due to human interventions to the coasts. These risks are of two kinds (i) short term risks associated with storms, swells, reclamation pollution, etc., and (ii) long-term risks related to climate change, sea level rise, damming of the river, coastal protection measures, etc. Often, it is a mixture of these two effects. In this paper, author's present only oil pollution effects on coral reefs. The coastal zone of the Red Sea on the Egyptian side is generally narrow because a mountain chain runs relatively close to the shoreline. The coast is composed of a large number of small bays or gulfs, and small beaches. The area has a large number of well-known diving centers because of its rich and highly diversified coral and mangrove communities. Major resort cities as shown in Figure 1.1 are Dhahab, Hurghada, Nuweiba, Marsa Alam, Ras Sidr, Safaga and Sharm El-Shikh (11).

Figure 1.1 Egyptian part of Red sea map

This paper reviews our present knowledge on oil pollution effects on coral reefs due to collision and grounding of ships in Egyptian coastal water and present modelling for damage assessment for these impacts.

2. Impacts on Coral Reefs Due to Oil Spill

Severe damage to corals may result in a collapse of the complex community of organisms, which live in close association with the corals. Concern for damaging effects of oil pollution on coral-reef communities is currently growing (10).

The global importance of petroleum and the resulting maritime traffic poses a serious threat to the fragile coastal and marine environments of the semi-enclosed waters of the Region. Routine operational leaks and spills from the production and transport of oil constitute the major source of marine pollution. At the same time, the growing risk of oil traffic-related accidents urgently requires emergency response plans combined with management skills to minimize risks. In contrast to other regional seas around the world where most pollution comes from land based activities, the main source of marine pollution in the Region is from ship-based sources, in which millions of tonnes per annum pass through the region (more than 20 oil spills occurred along the Egyptian Red Sea since 1982), oil exploitation and offshore oil production. While production and transport of oil continue to play a critical role in the Region's economy, they also constitute major sources of marine pollution. The marine pollution could be derived through the discharge of oily ballast water and tank washings by vessels, operational spills from vessels loading or unloading at port, accidental spills from grounded vessels, collision of ships, and leaks from vessels in transit (18, 23).

Oil spills can cause a wide range of impacts in the marine environment and are often portrayed by the media as 'environmental disasters' with dire consequences predicted for the survival of coral reefs, marine flora and fauna. In a major incident the short-term environmental impact can be severe, causing serious distress to ecosystems, coral reefs and to the people living near the contaminated coastline, affecting their livelihoods and impairing their quality of life (9).

The effects of spill response operations in coral reef environments must be viewed as one of many anthropogenic and natural impacts that affect corals worldwide. These include both global impacts, such as sea surface warming and increasing levels of carbon dioxide, and local impacts such as land-based pollutants, sedimentation, overfishing, and physical disturbances. Global warming detrimentally impacts coral in several ways. Levels of atmospheric carbon dioxide are increasing, causing rises in Sea Surface Temperature (SST), and this, in turn, increases the frequency and severity of coral bleaching. Levels of carbon dioxide are also increasing in seawater, resulting in weaker coral skeletons, reduced coral extension (growth) rates, and an increased susceptibility to erosion on reefs. Global warming is also linked to greater frequencies of severe storms, which are a major cause of physical damage to reefs (5).

Globally, and locally, coral reefs face a variety of threats and many have suffered severe degradation. These are common resources; they form part of our natural heritage. When damage is caused to these resources, compensation should be paid by the perpetrator and efforts should be made to restore the damaged area so that it continues to provide the physical and biological benefits to society (17).

However, coral reefs are declining at an alarming rate worldwide. This decline is mostly due to a large variety of human impacts that include local activities to large scale and global changes (8). It is estimated that 20% of the world's coral reefs have been effectively destroyed, 24% are under immediate risk of collapse, and a further 26% are under a longer term threat of collapse (24).

Coral reefs are highly productive areas which support a diverse group of organisms, including many commercial fish species. In Egypt they are often associated with commercially important dive sites. Coral reefs are easily damaged if oiled, may take several decades to recover if killed, and are difficult or impossible to clean. The susceptibility of coral reefs to oil damage depends on a number of factors: e.g. size of spill, type of oil, type and depth of coral reef, the local wave energy, the current stress of the corals, etc. In many cases oil slicks will float over reefs without causing damage to the submerged corals and associated organisms. Biological productivity per square meter of coral reef is usually 50 to 100 times more than in the surrounding oceanic waters. On a local scale, reef areas are an important fishery resource, are a barrier to coastal erosion, and their amenity value is often the basis of tourism development. Serious damage to corals can result from oil pollution. Research has shown that coral reefs can regenerate by natural processes after being oiled but there is still not a good understanding of the mechanisms and time scale involved. Recovery times can range from a few months for some species to effects lasting several years in cases of substantial damage caused by oil, especially when the corals are subjected to continual slow leaching of oil from nearby sediments. Some longer term studies have indicated that, while immediate mortalities in coral communities are rarely observed, coral death may in fact be observed several months after impact for reasons which remain unclear, although there is a correlation with coral depth. Furthermore, because of the difficulties of interpreting the true field significance of possible sublethal effects, corals affected by an oil spill require careful post-spill monitoring. Coral reefs are considered most sensitive to oiling (16).

3. Coral Reefs Types

3.1. Introduction

The National Oceanic and Atmospheric Administration (NOAA) defines coral reefs as "unique (e.g., the largest structures on Earth of biological origin) and complex systems" (14). Coral reefs are indeed a major marine ecosystem because those species diversity greatly exceeds that of any other marine environment. They are generally known as the rainforest of the oceans. It is assumed that, while their total area is less than 0.2% of the sea surface (22), coral reefs host almost 30% of all the marine biodiversity (i.e. 93,000 described coral reefs plant or animal on a total of 274,000 described marine species), Living animals, mainly coral colonies, produce coral reefs. These "reef-building corals" (= hard corals) secrete a hard skeleton made of aragonite, a form of calcium carbonate (limestone). This external skeleton then creates a 3D framework that forms a complex habitat, increasing species abundance and total productivity. Such limestone structures may reach 1.3 km thick and up to 2,000 km long. Following their shape, they are classified as fringing reefs (parallel to the coastline at a distance < 1 km from shore), barrier reefs (parallel to the coastline at a distance > 5 km from shore) or atoll reefs (12).

3.2. Types of Coral Reefs in Egypt

The coral reefs in the Egyptian part of Red Sea region are among the most spectacular in the world, supporting a high level of biodiversity with over 1000 named species and many more yet to be identified. Nevertheless, coral reefs usually have a relatively high growth-rate. The warm water and absence of freshwater input provide very suitable conditions for coral reef formation adjacent to the coastline. In the northern Red Sea the coast is fringed by an almost continuous band of coral reef, which physically protects the nearby shoreline. This beautiful environment is extremely attractive as a tourist resource and is currently visited by hundreds of thousands of people each year, who dive, walk, and swim in the waters adjacent to the reefs. Further south the coastal shelf becomes much broader and shallower and the fringing reefs gradually disappear to be replaced by shallow, sandy shorelines and mangroves. Coral reefs also occur as offshore patch reefs and reefs fringing islands. They provide food and shelter for a large and diverse fauna and flora. Most fishing activities in the Region occur in shallow waters in the vicinity of coral reefs (15, 20, and 21).

Egypt is a large country with a relatively long portion of the Red Sea coastline, about 1,800 km including the coasts of the Gulf of Suez and Gulf of Aqaba. Most of the Egyptian coast of the Red Sea is bordered with a coastal fringing reef except for parts of the Gulf of Suez. The width of the fringing reef ranges from 10 m up to 1,500 m especially on the southern part of the coast. In addition to the fringing reef a large number of submerged reefs are present especially in the area between the coast and the nearby offshore islands (17).

Coral reefs are structures built on a hard surface and found in oceans, seas and lagoons. The main types of coral reef are classified as (7, 13):

Fringing Reef: This is the most common type of reef as shown in Figure 3.2.1; this type of reef is directly attached to the shore. Fringing reefs grow quickly in shallow water but their growth further away from shore is slower. Fringing reefs have a shallow platform that spreads outward to a sharply defined edge. Imagine the reef like a shelve with an edge that drops down to the sea floor.

Figure 3.2.1 Fringing reef

Barrier Reef: Barrier reefs are often some distance from the coast as shown in Figure 3.2.2. Some barrier reefs are attached to fringing reefs on shelving coastlines. In other cases these reefs may have developed in offshore places. Sometimes a lagoon separates a barrier reef from the coast.

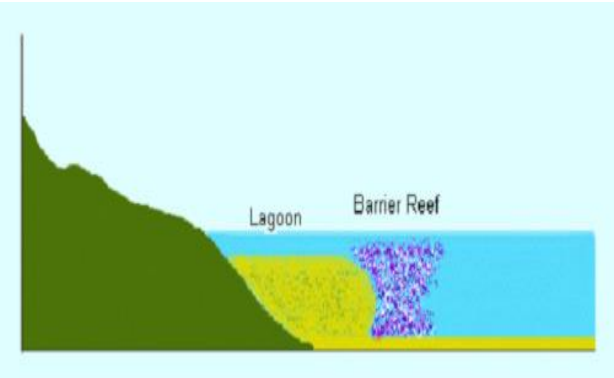

Figure 3.2.2 Barrier reefs

Atoll Reef: An atoll (Figure 3.2.3) is formed when a reef grows in a pyramid shape, rather like a volcano. A lagoon forms in the center of the surrounding reef and smaller reefs may grow inside this lagoon.

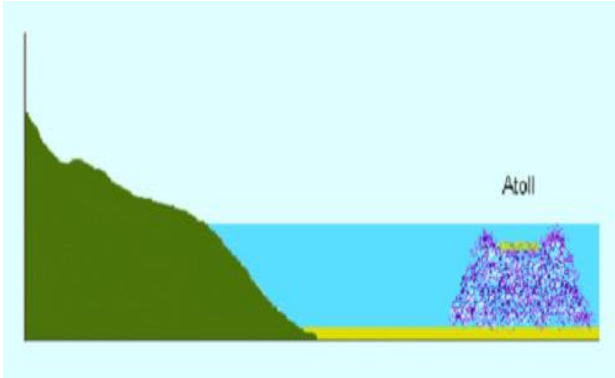

Figure 3.2.3 Atoll reef

Patch Reef: Patch reefs communities are found in waters at depths from 10 to 30 feet. The outer edge of each patch reef is surrounded by a ring of sand. It is the feeding fish that determine how wide this sand ring is. If the fish feel safe close to the reef then the sand ring will be narrow. A wide ring of sand means that the feeding fish feel safe further away from the reef. Each patch reef is different in size, development, and species living on them. Mostly large colonies of star and brain corals make up this reef type.

Bank or Platform Reef: Bank reefs (Figure 3.2.4) are found in deeper waters than the patch reefs of near-shore environments at depths from 20 to 60 feet. Bank reefs are significantly larger than patch reefs and are common dive and snorkel destinations. Bank reefs also have high species diversity, meaning many kinds of animals and plants live on and around this type of reef. Bank reefs have something special called spur and groove patterns. The spur and groove formation is made up of low ridges of corals (spurs) separated by sandy bottom channels (grooves). The most commonly found corals are Elkhorn, staghorn, seafans, sea whips and brain corals.

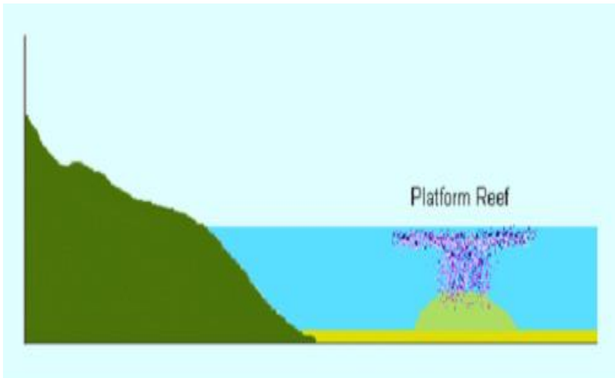

Figure 3.2.4 Platform or Bank reef

Different Kinds of Coral reefs come in a variety of shapes, sizes and colour. But in general there are two types of corals as shown in Figure 3.2.5: Soft Corals and Hard Corals. Soft Corals; called soft corals because they do not have hard, rigid permanent skeletons, this group is made up of the Gorgonians and the Black Corals. Hard Corals; this group is made up of the hydrocorals and the stony corals. Both types of coral have hard skeletons made of calcium carbonate.

Figure 3.2.5 Soft Corals and Hard Corals

4. Statistical Data for Oil Spill in Red Sea Region

In 1987 the management of the protected area of Ras Mohamed issued a report about the increase in the number of ships grounding in the Gulf of Aqaba, especially in the Tiran island area (more than 10 ships). The report concluded that most of the accidents were deliberate for obtaining insurance money. As a result of this report, the Egyptian Environmental Affairs Agency started to deal with ship grounding accidents as a threat to the marine environment. The first case was that of the ship LANIA carrying the flag of Holland which collided with the reef and spilled about 700 tons of fuel into the water. The damage was estimated at $100 million. However, due to the lack of scientific basis in evaluating the damage the compensation was reduced to $0.75 million. The same situation was repeated in the accident involving the ship SAFIR which collided with the reef leaking a vast amount of phosphate ore onto the reef. Also in this case compensation was reduced due to the lack of scientific basis for the valuation (17).

The officially recorded numbers of ship/boat groundings, from 1987 and up till July 2008, in South Sinai and the Red Sea coast (i.e. off Hurghada and the rest of the Egyptian Red Sea) is 69 and 80 respectively (i.e. a total of 149 incidents). The incidents included 22 large accidents caused mostly by cargo ships colliding with the reefs (14 in the Gulf of Aqaba and 8 on the Red Sea coast). The total damage to the reefs was valued at $75,634,712 split between the Gulf of Aqaba ($68,899,056) and the Red Sea coast ($6,449,888). The records also show that 73 accidents were caused by live-aboard boats (55 in the Gulf of Aqaba and 18 on the Red Sea coast) causing an estimated $1,238,791 worth of damage, while 38 small day-boat accidents occurred on the Red Sea coast with damage losses estimated at $755,484 (17).

In the northern section of the Egyptian Red Sea most of the accidents happened on the submerged reefs around the Tiran Islands at the entrance to the Gulf of Aqaba, and on the southern tip of Ras Mohamed where a large number of small patch reefs occur. On the Red Sea coast accidents were concentrated at the entrance to the Gulf of Suez especially in the area known as ASHRAFY Reefs and around the northern island group. In addition, accidents also occurred on the submerged reefs around Hurghada Islands and, with less frequency, on the coastal fringing reefs to the south (17).

5. Methodology for Coral Reefs Damage Assessment in Case of Oil Spills in the Egyptian Coastal Water

In the early 1980s, with the declaration of Ras Mohamed as a Marine National Park, a set of rules and regulations were applied to the area in order to protect the marine environment from damage which might be inflicted due to development. Many of these rules and regulations applied to parts of the coast under the umbrella of Law 102, issued for organizing the protected areas. Several marine protected areas were declared in the following years to cover almost all the coast of the Gulf of Aqaba and parts of the Egyptian Red Sea coast (17).

Also at the end of the 1980s, the European Union financed a project for the development of protected areas in South Sinai. The project management found the opportunity to form a special task force to solve the problem of valuation of the coral reefs using scientific methods. Since 1992, the regulations were applied in all areas with protected status such as protected areas and environmental management areas. The method of calculation was also recognized by law courts, insurance companies, and ship owners' clubs and the Egyptian legal system was able to claim millions of dollars in compensation for reef damage. The procedure was presented at the International Coral Reef Symposium in 1996 (17).

In June 1997, the responsibility of Egypt's first full time Minister of State for Environmental Affairs was assigned as stated in the Presidential Decree no. 275/1997. From thereon, the new ministry has focused, in close collaboration with the national and international development partners, on defining environmental policies, setting priorities and implementing initiatives within a context of sustainable development. According to the Law 4/1994 for the Protection of the Environment, the Egyptian Environmental Affairs Agency (EEAA) was restructured with the new mandate to substitute the institution initially established in 1982. EEAA represents the executive arm of the Ministry (3).

Three basic environmental laws are of particular relevance to coral reefs in Egypt. They are law 102 of July 1983, which is concise and specifically aimed at protected areas. Law No. 124/1983 on fishing, aquatic life and the regulation of fish farms prohibits, among other regulations, the use of poisonous and explosive substances in fishing activities. Law 4 of January 1994 is more general in scope and prohibits the collection of corals, shellfish and other marine life in all Egyptian waters. Most of the regulations that are applicable in the

Red Sea nowadays are based on a protocol signed between the Red Sea Governorate, the EEAA and HEPCA (Hurghada Environmental Protection and Conservation Association). It was stated in a governor's decree of the year 2000 that any violator for the internal regulations of the Red Sea Governorate drafted by the National Parks department will be fined according to the assessment of damage and this assessment will be done by the National Parks (6).

Egypt has taken the lead in the development of valuation techniques and pursing legal remedies to achieve compensation payments. The basic model developed by Egypt as "Eq (1)" and used to a greater or lesser extent within the region is as follows:

$$Compensation\ Charge = A \times LC \times D \times RP \times V \qquad (1)$$

Where:

A : is a measure of area or impacted area in square meters (m^2),

LC: is the percentage of living coral,

D : is the percentage damage in the area,

RP: is the number years required for recovery and,

V : is the value of one square meter of the reef. (V: set at US $120 in 1992 but now increased to US $300 for national parks).

The above formula was issued in January 1992 and was applied in all areas with protected status such as protected areas and environmental management areas. The method of calculation was also recognized by law courts, insurance companies, and ship owners' clubs and the Egyptian legal system was able to claim millions of dollars in compensation for reef damage (17).

6. Integrated Oil Spill Damage Assessment Model (OSDAM)

This paper focuses on and presents the Modelling of the coral reefs damage assessment in case of oil spills in the Egyptian coastal water based on the EEAA methodology. The proposed OIL SPILL DAMAGE ASSESSMENT MODEL (OSDAM), a part of integrated model for simulating of spill trajectory and Environmental Damage (i.e. Coral Reefs & Shoreline) and Economical Damage assessment, was designed as an oil spill support tool for emergency responder and contingency planners to estimate whether the economical and environmental impacts as a result of oil spill in coastal water of Egyptian. Figure 5.1 shows snap shot of Oil Spill Damage Assessment Model. Using Geographic Information System (GIS), the authors' implement an integrated automated system between the OSDAM and Oil Spill Trajectory Model to assess the damage of the impacted type of coral reefs directly.

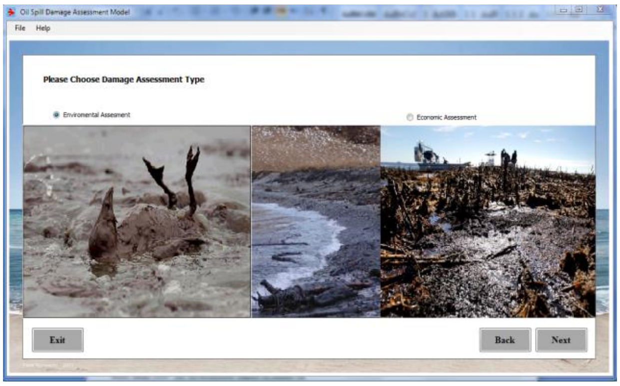

Figure 6.1 Snap shot - Oil Spill Damage Assessment Model

OSDAM contains the types of common coral reefs, in addition to if the type of coral reefs is not found in the types in OSDAM the user can put the reef type and its specification into the program by himself and is called in the model (custom reef). Figure 5.2 shows snap shot of OSDAM environmental damaged assessment.

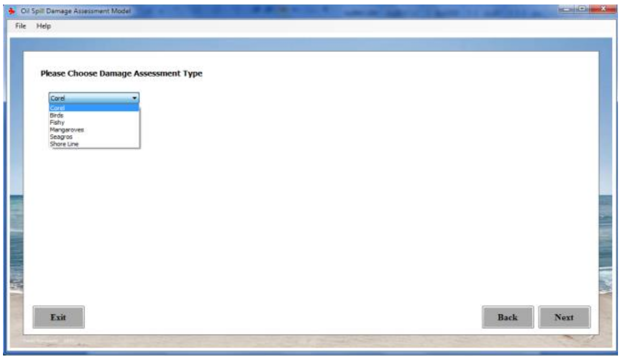

Figure 6.2 Snap shot - OSDAM Coral reefs damaged assessment

In this paper only the environmental impacts studied (especially coral reefs), Figure 5.3 shows coral reef mapping in the Egyptian part of Red Sea region. The economical impacts will treat later. The input data required of the incident to run the program are type of coral reef, the impacted area of coral reefs in square meters, the percentage of living coral, the percentage damaged in the area of coral reefs, number years required to recovery the coral reefs and value of one square meter of coral reefs (now set at US $300 for national parks). Figure 5.4 shows Snap shot - OSDAM data entry screen.

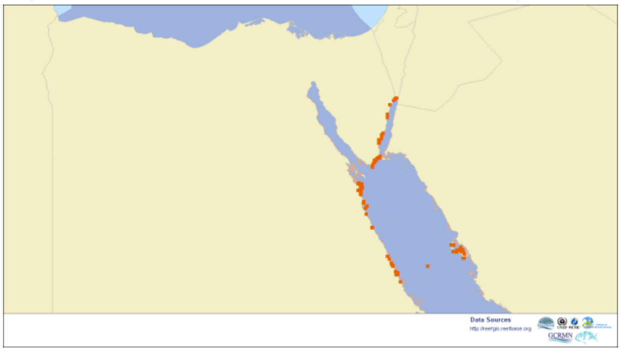

Figure 5.3 Coral reef mapping in the Egyptian part of Red Sea region, (19)

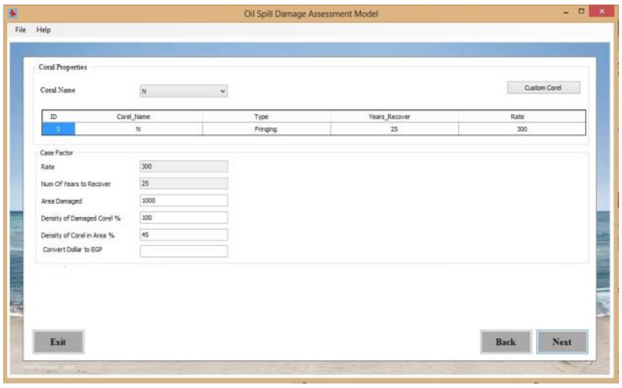

Figure 5.4 Snap shot - OSDAM data entry screen

7. Assumptions & Implementation for Simulated Scenarios

It is extremely important that an assessment be conducted as soon after the incident as possible so that damage to biota and the substrate can be easily identified, measured and documented with still and video cameras.

Responders and planners feed the OSDAM model with the appropriate input data. Two assumed scenarios of coral reef impacts assess were investigated by the OSDAM model and the assumed data are shown in Table 1.

Table 1: Shows the two scenarios of coral reefs impact

Inputs	Scenario 1	Scenario 2
Coral reefs type	Fringing reef	Fringing reef
A: Impacted area : m^2	1000	1000
LC: % of living coral	45 %	45 %
D: % damaged of area	100 %	60 %
RP: number of years required for coral reefs recovery	25	15
V: value of 1 m^2	300 $	300 $
Total damaged assessment in coral reefs in American dollars ($)	3,375,000	1,215,000

The total damaged assessment for assumed scenario 1 and scenario 2 is shown in Figure 6.1 and Figure 6.2 respectively. The OSDAM estimates the coral reefs damage due to oil spill as in scenario 1 and scenario 2.

Scenario 1: the model fed with the following inputs: Fringing coral reefs type, the impacted area is 1000 m^2, percentage of living coral is 45% with damage area percentage of coral reef is 100%, and Twenty five years for coral reefs recovery. The model assessed the total damaged assessment in coral reefs as 3,375,000 $.

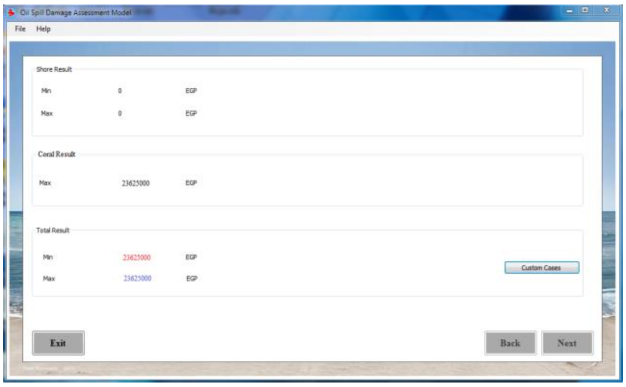

Figure 7.1 OSDAM total damaged assessment for scenario 1

Scenario 2: the model simulates the coral reefs damage assessment for different percentage of living coral types, the OSDAM fed with the same Fringing coral reefs type, the impacted area is 1000 m^2, percentage of living coral is 45% with damage area percentage of coral reef is 60%, and Fifteen years for coral reefs recovery. The model assessed the total damaged assessment in coral reefs as 1,215,000 $.

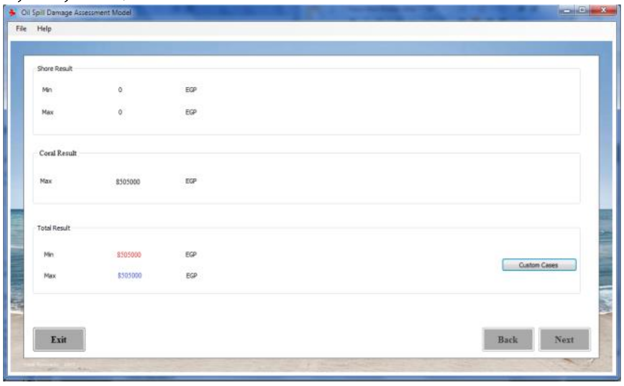

Figure 7.2 OSDAM total damaged assessment for scenario 2

8. Conclusion

The important coastal and marine environments and resources of the Egyptian Red Sea is subject to a series of individual and cumulative threats which have significant short- or long-term consequences for sustainable development in the Egyptian part of Red Sea region. Coral reefs are recognized as important ecosystems, contributing significantly to livelihoods and income in many countries. The advent of laws demanding compensation for damage to coral reef and the amount paid in fines has been shown to have a positive effect on the number of accidents recorded; they have gone down. It is suggested that countries in the Red Sea and Gulf should adopt similar formulas as Egypt for compensation into existing national environmental laws as a further deterrent against environmental degradation. This paper focuses on and presents impact of coral reefs, threats to coral reef environments in the Egypt coral reefs types in Egypt, a proposed OIL SPILL DAMAGE ASSESSMENT MODEL (OSDAM) which facilitates the damage assessment for the planners and assessors in case of oil spills in the Egyptian coastal water based on the EEAA methodology used for estimating coral reefs impact in Egypt.

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The group is very interesting in the fields of marine environmental protection and risk management. The group is interesting in using predictive mathematical models to simulate the environmental crises which are very useful for decision makers to optimize the corresponding response options which support and improve decisions in real situations.