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RESEARCH ARTICLE

ENVIRONMENTAL POLLUTION RISKS OF OIL SEEPAGES FROM FSO-SAFER AND FUTURE PREDICTION MODEL ON RED SEA COAST, AL-HODEIDA, WEST YEMEN

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ARTICLE DETAILS

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ABSTRACT

Yemeni coasts are subjected to several oil spills incidents since 2013 such as the Champion vessel disaster in Mukallah-Arabian Sea, and the massive oil slicks along the coast of Aden in 2021 caused by the leaks abandoned tanker, DIA and sink. This paper aimed to study the environmental impacts of the floating oil storage (FSO Safer) loaded by 1.14 million barrels oil and has been left exposed to humidity, corrosion and lack of maintenance since 2015. The field data were collected during the period 2010 and 2015 through various population surveys, biodiversity monitoring and conducting water analysis in the Ras Issa region, as well as monitoring and follow-up the status of FSO_SAFER during 2018-2022. The results revealed deterioration in environmental biodiversity especially in the coral reefs, while sea water characteristics are changed by oil contamination. In Ras Issa locality, high concentration of petroleum hydrocarbons were recorded i. 12.8 ppm in sample 1 and 3. Verities of heavy elements i.e. As, Cd, Fe, and Ni are exceeding the permissible levels. The present study is highlighted the subsequences scenarios for leaks oil from FSO_SAFER's and expected pollution, while the estimated tackle cost of compensation and damage to environment, clean up, technical work and contingency is reaching up to \$26.1 billion.

KEYWORDS

FSO-Safer vessel, Red Sea Coast, pollution risk, coastal/marine environments, Ras Issa peninsula, Yemen.

1. INTRODUCTION

The coastlines of Yemen are extended for 2,252 km, and 770 km along the Red Sea (Nagi, 2021), having marine natural resources of unique characteristics, which is usually suffer due to the petroleum pollution (EPA Yemen, 2014, 2016, 2019). Recently, the Red Sea coast is exposing to oil leaks from the FSO_SAFER tank in Ras Issa, in Al-Hodeida district. Prevent of international maintenance teams to repair damage in the Safer tank led to seep massive quantities of stored oil could be result of massive oil disaster. The Yemeni costs are rich in coral reefs communities, having about 300 fish species lived in (EPA Yemen, 2019). The ecosystems and biodiversity needs coastal protection and entertainment, which constitute approximately 10% of the world's fisheries contributing 25% of fishing in developing countries (<http://coris.noaa.gov/>).

This paper addresses Ras Issa area that comprised various environments, socio-economic situation and site and the state of the FSO_SAFER, explaining deterioration of marine environments (coral reefs or change of seawater properties) with potential risks of oil pollution caused by oil spill from the storage tank.

2. MATERIALS AND METHODS

2.1 Study Area

Ras Issa peninsula is located near Salif Petroleum port in the red Sea coast in Al-Hodeidah governorate, W Yemen (Figure. 1) (NIC Yemen). It is a coastal flat land interspersed by simple heights maximum of 17m a.s.l, characterizing by arid climate (Al-Kharraz, 2010).

Field data was collected by monitoring, diving and field surveys for

population, biodiversity and water analyses during 5 years period from 2010-2015. Moreover, reports, monitoring and follow-up the status of were carried out.

2.2 FSO_SAFER location

FSO_SAFER tank is located in the Red Sea, 8 km far from the maritime off shore area of Ras Issa (Figure. 1). The area comprised particularly exposed risk extent in Ras Issa and in Yemeni coast to the city of Hodeidah as the catastrophic event from FSO_SAFER, whether by leaks or explosion.

2.3 Data Collection

Population data, services and activities are collected by field survey, directly from village's notable in the council of Salif district (Period 2010 – 2015), and compared with the last government survey in 2004. The collected data includes population, houses number, roads, available services, water sources, causes of increase or decrease of natural resources and environmental issues (Table 1).

2.4 Water sampling and analysis

Seventeen water samples are collected from three site in Ras Issa area (Figure. 1) during two periods, (2010 and 2015) accompanied by survey and evaluation of biodiversity life. Sea water samples are analyzed to determine the heavy metals and organic matter content (Table 4 and 5), analyzed in lab of the Authority for Water Resources/Ministry of Water and Environment. Figure. 2 shows collect of sea water samples at depth of 0.5 m. The 1st stage is analyzed of the seawater properties and 2nd stage is to measure of indicative-polluted elements such as minerals and petroleum oils.

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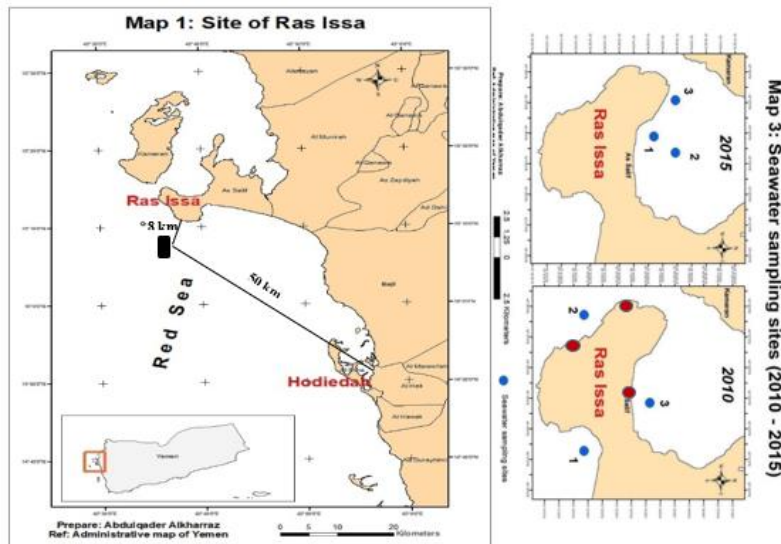


Figure 1: Location map shows the study area in Ras Issa Peninsula in Al-Hodeidah district with location of FSO-Safer tank. The blue dots refer to the sites of the water sampling during 2010 and 2015. The red dots in lower right map shows the site of the resting birds in the area (2010 survey).

| Table 1: Location of Sampling Points and their Co-ordinates. | | | |
|--|---|---|---|
| Field works | Al-Zuhaifie Village (Island) | Dhabra Village | Wali Village |
| Coordinates | N: 15.22694 E: 42.6610 | N: 15.21226 E: 42.6261 | N: 15.18915 E: 42.6623 |
| Noisiness in decibels | 85.6 | 80.6 | 85.5 |
| Distance from Al-Hodeidah City Km | 60 – 70 km | 60 – 70 km | 60 – 70 km |
| Distance from main roads Km | 1.3 | 2 | 3.5 |
| Population | Total = 1450 people Males = 52%, Females = 48% children = 30% | Total = 335 people Males = 52%, Females = 48%, children = 30% | Total = 980 people Males = 51%, Females = 49%, children = 30% |
| No. of houses | 22456 | 56 | 135 |
| types of roads | sandy | sandy | sandy |
| service available | Electricity - Safer Company June 2014 Water - Local Council High school established in 2010 Government Health Unit | Electricity - Safer Company June 2014 Water - the local council (the funder) 3 years ago Preparatory schools - government Literacy schools | Electricity - Safer Company June 2014 Water is not the whole village - the government Health unit - government Old School - Government (6 classes) |
| Services not available | Doctors staff for the health unit asphalted roads transportation Sanitation | Health Unit high schools Asphalt roads and transport Sanitation | high schools Water project for the village Sanitation transportation advanced health units |
| Reasons of lack services | Claimants' absence Lack of interest from officials and investors | Claimants' absence Lack of interest from officials and investors | Claimants' absence Lack of interest from officials and investors |
| water resources | government project | government project | government project |
| educational interest | in existence | in existence | in existence |
| Most important activities of positive impact for population | fishing | Fishing, Job Opportunities in Sugar Factory and Safer Co. | Fishing, Job Opportunities in Sugar Factory and Safer Co. |
| Most important activities of negative impact for population | Bad smells from the sugar factory's tube | Zero | Zero |
| Nearest markets | Village market | Zuhaifi and Salif Market | Zuhaifi Market |
| No. of times to visit market | Every day | Daily in Zuhafi Market Monthly Salif and Hodeida Market | All week from Zuhafi Market Once or twice a month from the Hodeidah or Salif market |
| Important agricultural crops | No crops | watermelon + fodder + corn (during the rains) | None, only during rainfall |
| Existing trees | Frenula alus tree. Ziziphus spine+ Basil. Ocimum Basilicum | Neem tree. Azdirachta+ Frenula alus tree. Ziziphus spine+ Basil. Ocimum Basilicum | Neem tree. Azdirachta+ Frenula alus tree Ziziphus spine+ basil. Ocimum Basilicum |
| Utilization of natural resources | Fishing fishing rent boat | Fishing, boat making, and rent, fodder for livestock | Sea for fishing only |
| causes of increase or decrease of natural resources | No resources other than the sea | Shortage of natural resources due to land grabbing lack of rainfall | Decreased compared to last decade due to damage of industrial activities and lack of rainfall |
| Three most important problems of the population | Unemployment, illness and poverty | lack of education, disease and awareness | Lack of government jobs, permanent business availability Unemployment, education and poverty |
| Environmental issues | Lack of sewage and treatment networks, garbage dumps and pollution problems from the Safer oil facility | | |

3. RESULT

3.1 Sea Water Analysis

Two stages are selected to collect and analyzed the sea water samples during 2010 and 2015 to see the effect of pollution impact from FSO_SAFER vessel. The data are shown in (Table 2, 3).

3.1.1 First Stage 2010

The first stage is to test the physical and chemical properties of seawater in the three sites (Table 2). Site 3 show less turbidity than site 1 and 2. The analytical results show no significant differences between seawater in the three sites.

3.1.2 Second Stage 2015

This stage is to analyze the collected water samples to estimate the oil pollution indicators. Site 1 is lying 10 m away from the quay of port (coordinates N °15.251953 and E ° 42.614416). Site 2 is 300 m from the coast (coordinates N °15.254241 and E °42.615908). Site 3 lies opposite the bird gathering site, 30 m from the coast (coordinates N ° 15.253812 ° 15.253812 and E ° 42.611605).

All samples show high concentrations of organic matter (TVC), reaches 10000 ppm indicating significant pollution. Organic hydrocarbons concentration in sample 3 is high and reach 12.8 ppm more the other sites (Table 3). Sample 1 shows some heavy metals concentration (i.e. As, Cd, Fe, Ni) more than permissible levels. The removal damage cost of oil from FSO_SAFER is estimated depending on many laws and experience in environmental assessment of oil pollution in Yemen.

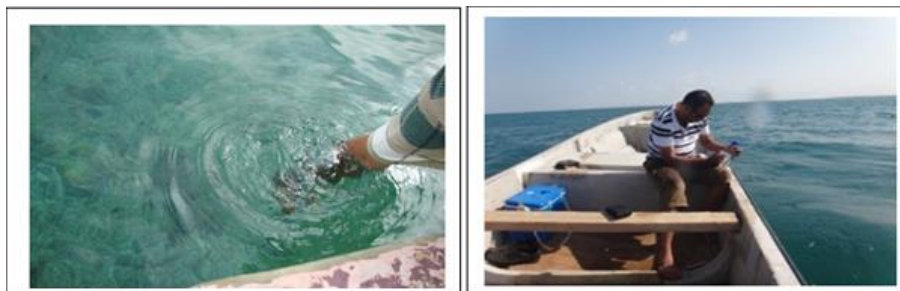


Figure 2: Shows the process of collecting surface water samples from the sea in Ras Issa (2010 – 2015).

Table 2: Show results of seawater analysis at selected sites during 2010.

| Parameter | Unit | Site 1 | Site 2 | Site 3 |
|---------------|-------|--------|--------|--------|
| pH | - | 7.57 | 7.66 | 7.84 |
| Color | Pt-Co | 25 | 5 | 13 |
| Turbidity | NTU | 6.5 | 2.5 | 3 |
| EC | µS/cm | 57000 | 56900 | 56600 |
| TDS | mg/L | 37980 | 37940 | 37880 |
| T. Hardness | mg/L | 6755 | 7056 | 6982 |
| T. Alkalinity | mg/L | 163 | 129 | 129 |
| HCO3 | mg/L | 199 | 157 | 157 |
| Cl | mg/L | 20492 | 21583 | 20811 |
| F | mg/L | 1.92 | 1.91 | 1.91 |
| SO4 | mg/L | 2700 | 2800 | 2850 |
| NO3 | mg/L | 5.72 | 2.2 | 3.96 |
| NO2 | mg/L | 0.03 | 0.014 | 0.007 |
| PO4-3 | mg/L | 0.05 | 0.06 | 0.01 |
| Na | mg/L | 11880 | 11000 | 11520 |
| K | mg/L | 440 | 440 | 455 |
| Mg | mg/L | 1389 | 1462 | 1452 |
| Ca | mg/L | 414 | 415 | 401 |
| Fe | mg/L | 0.03 | 0.02 | 0.01 |
| Cu | mg/L | 1.7 | 0.75 | 2.88 |
| Cr | mg/L | 0.01 | 0.02 | 0.02 |
| Cd | mg/L | 0.06 | 0.11 | 0 |
| Zn | mg/L | 0.19 | 0.23 | 0.12 |

Table 3: Show results of sea water analysis at selected sites during 2015.

| No. | Parameters | Site 1 (ppm) | Site 2 (ppm) | Site 3 (ppm) | EPA US (mg/L) |
|-----|--------------|--------------|--------------|--------------|---------------|
| 1 | COD | 4.4 | 3.4 | 1.2 | |
| 2 | Oil & Grease | 3.2 | 2 | 12.8 | |
| 3 | TS | 42650 | 41410 | 39210 | |
| 4 | TVS | 10320 | 10350 | 10000 | |
| 5 | As | 1.89 | Nil | Nil | 0.010 |
| 6 | Cd | 0.20 | Nil | Nil | 0.005 |
| 7 | Co | 0.43 | Nil | Nil | |
| 8 | Cr | 0.29 | 0.11 | Nil | 0.1 |
| 9 | Cu | 0.19 | Nil | Nil | 1.3-1.0 |
| 10 | Fe | 0.32 | 0.15 | 0.15 | 0.3 |
| 11 | Mn | 0.22 | 0.06 | 0.04 | 0.05 |
| 12 | Mo | 0.32 | 0.54 | 0.55 | |
| 13 | Ni | 0.30 | 0.40 | 0.21 | |
| 14 | Pb | Nil | Nil | Nil | 0.015 |
| 15 | Se | Nil | Nil | Nil | 0.05 |
| 16 | V | 0.30 | Nil | Nil | |
| 17 | Zn | 0.76 | 0.36 | 0.39 | 5 |

3.2 Demographic Changes and Infrastructure

The rate of annual growth in 2015 is 4.7% according to Yemen's Central Bureau of Statistics / Ministry of Planning and International Cooperation (CSO Yemen, 2004). Figure. 3 show increases from 2441 person in 2010 to 2765 person in 2015, while Al-Zuhayfi (island), Al-Wali (Issa) and Al-Dhabra shows no significant population changes. The men are working in various activities i.e. fishing and fishing boats, factories and in Safer oil

pumping station, with simple works. The area is poor in national electricity, potable water, health care services and in education (primary schools only). All water wells in the area are not suitable to drink. The sewage or garbage dump services are absence. Ras Issa population is suffered from many environmental and social issues i.e. drinking water, sanitation, educational structures and employment opportunities. Significant pollution is recorded from Safer oil tank, affecting seawater or waste discharge to the areas.

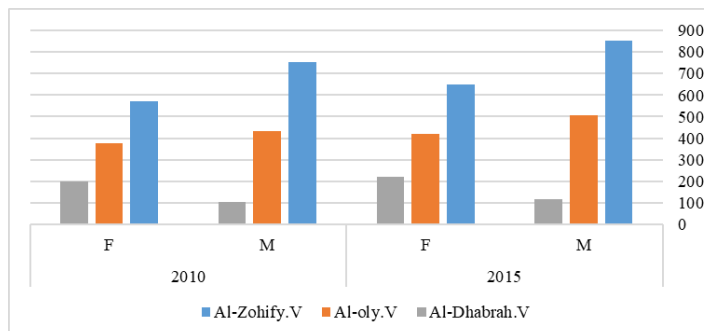


Figure 3: Population Survey during 2010 to 2015 of Villages of Ras Issa Peninsula (F- Female, M- Male).

3.3 Biodiversity Degradation

Ras Issa coastal environment and surrounding areas are rich in distinctive varieties of marine life, animals, plants and birds. It represents migration passage way for many birds' species. Specific survey (2010 to 2015) was done to monitor the coastal biodiversity using diving to monitor the coral reef (Al-Karraz, 2010A; Al-Karraz, 2011A; Al-Karraz, 2014A; Al-Karraz, 2015A). The plant varieties are ideal community of hot coastal environment and saline gypsum soil, scattering in Tehama plain, with small size of few single or tree groups.

The area represents sabkha environment and the flora types are distributed adjacent to the coast where majority of flora community is *Zygophyllum sp.* (PI/A) with less of *Suaeda fruticosa* and *Blepharis edulis*

species (PI/1B).

The villages of Al-Zuhaifi and Al-Dabra show low density types of *Hyphaene thebaica* (PI/1C), while near Dhubra village show *Tamarix sp.*, *Silvadora persica sp.*, and *Ziziphus sp.* (PI/1D). The short shrubs of *Limonium sp.*, *Suaeda fruticosa sp.* and *Aeluropus lagopoides sp.* are observed also.

The seasonal low mass water currents flowing from Gulf of Aden to the Red Sea are carrying large amount of nutrients enrich the cost with high biodiversity (Alsaafani and Shenoi, 2004). Biodiversity life are differs according to the seabed types i.e. gravel, sand or rock and it is particularly affected by oil leaks, which are discussed in the following:

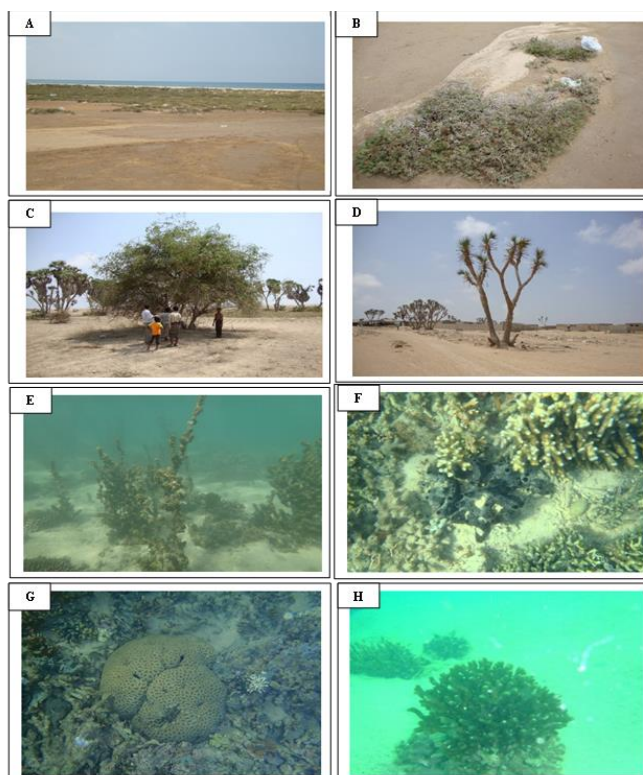


Figure 4 : The biodiversity of fauna and flora identified in Ras Issa studied area.

A) *Rattlesnake Zygophyllum sp.* from N-coasts (2010), **B)** *Blepharis edulis sp.* from N-coastal sabkha (2010), **C)** *Hyphaene thebaica* tree close to center of Al-Zuhayfi and Al-Dhabra villages (2011), **D)** *Ziziphus sp.* tree near Dabbara village (2015), **E)** *Trbinaria sp.* marine weed (2015), **F & G)** Different types of corals destroyed by high rate of sedimentation (2015), **H)** Hard coral, *Stylophora pistillata sp.*

The seaweed *Trbinaria sp.* (PI/1E) is observed in the deep margin, represents significant ecological impact on the food chain. At a depth of 10 m, colonies of *Stylophora pistillata* and *Platygyra lamellina sp.* (PI/F,G,H; PI/2A,B) have been completely buried by flaccid coral colonies (xeniids *sp.*). In addition to the sediment supply, the coral reefs are damage by

lunch anchor and fish hunters to catch for food fish or ornamental fish (Table 4, 5).

The coralline algal colonies are also observed (PI/2C). The creeping alga acts to secrete calcium carbonate cement to bind and solidify coral

structure together (Bak R.P.M. 1976). The Red Sea coasts comprise one of the most beautiful and important reef areas in the world. Large varieties of coral reefs are destroyed by sediment dump due to drilling and backfill operations. Symbiotic corals *Zooxanthella*. and crustaceans of *Penaeus semisulcatus sp.* are identified, with important sponge, using as cancer-resistant drugs act to immune system (Pan et al. 2011). Important sponge colonies are identified and of shelter significant for a number of marine lives such as sea stars, ringworms and shrimps (Pl/2G). Surveyed corals types are listed in Table 4.

Varieties of snails (gastropod) large quantities have been observed (Pl/2D) and some types are without thorns. Varieties of bivalve are available and the smooth type is the most common species. Echinoderms are lived in shallow bottom water near the shore and in deep waters (Rashed et al. 2018). Black Urchin *Diadema* are observed of Sea (Pl/2E) present on bed rocks and reefs.

Table 4: Shows the Families and Species of Coral Reef Identified in the Area During 2015.

| Family | Species |
|----------------|-------------------------------|
| Xeniidae | xeniidae |
| Pocilloporidae | <i>Pocillopora damicornis</i> |
| | <i>Pocillopora verrucosa</i> |
| | <i>Stylophora pistillata</i> |
| Acroporidae | <i>Acropora hemprichii</i> |
| | <i>Acropora microclados</i> |
| | <i>Acropora sp</i> |
| Poritidae | <i>Porites lutea</i> |
| | <i>Porites nodifera</i> |
| Oclinidae | <i>Galaxea fascicularis</i> |
| Fungiidae | <i>Fungites sp.</i> |
| Favidae | <i>Faviia fava sp.</i> |
| | <i>Favites sp</i> |
| | <i>Echinopora lamellosa</i> |
| | <i>Echinopora gemmecea</i> |
| | <i>Goniastrea retiformis</i> |
| | <i>Platygyra lamellina</i> |

Sea cucumbers are also found (Pl/2F) as economic income source to prefer food for foreign countries. Sea stars (Pl/2G), fragile sea stars (Pl/2H) with types of sponges and posesities (Pl/3A).

3.4 Marine Vertebrates

Marine vertebrates' types are important valuable food for many population communities (Australian Museum, 2007). More than 1280 species of fish were recorded in the Red Sea and comprised about 11-17% are endemic. (https://www.ncw.gov.sa/Ar/Wildlife/Biodiversity/Pages/Diversity_in_marine_fish.aspx).

The study area is rich in fish varieties, and several families and species were recorded (Table 5).

3.5 Important Site of Resting and Feeding of The Birds

Ras Issa area is a seabird habitat environment (Pl/3B,C), comprised a food chain and ecological balance, which is used as indicator for extend of petroleum contamination (Perez et al. 2017). The area is a feeding, breeding or resting site for these birds adopted certain plants i.e. *Zygophyllum sp.*, to build nests. During 2010 survey, five species were records (Pl/1A,B).

Figure. 1 shows the sites of the bird life in Ras Issa. Site 1 is located NW, three species of birds were recorded on, c.f. sooty gull (*Larus hemprichii sp.*), lives and breeds along the coasts and build the nests within the salty plant communities and feeds on crustaceans and fish. The white-eyed gull (*Larus leucophthalmus sp.*) builds the nests in the coastal plants. The Caspian Tern (*Sterna caspia sp.*) characterized by thick red beak, feeding on fish and nesting near the coast.

Black-backed Gull (*Larus fuscus sp.*) is one of most widespread seabirds, which lived in the site 2, far NW of Ras Issa area (Pl/3C). It is, feeding on small fish, crustaceans, and mollusks. The 5th type is Pink Pelican Pelican (*Pelecanus rufescens sp.*) live in site 3, NW of the Ras Issa and build the nests in mangroves (Pl/3D).

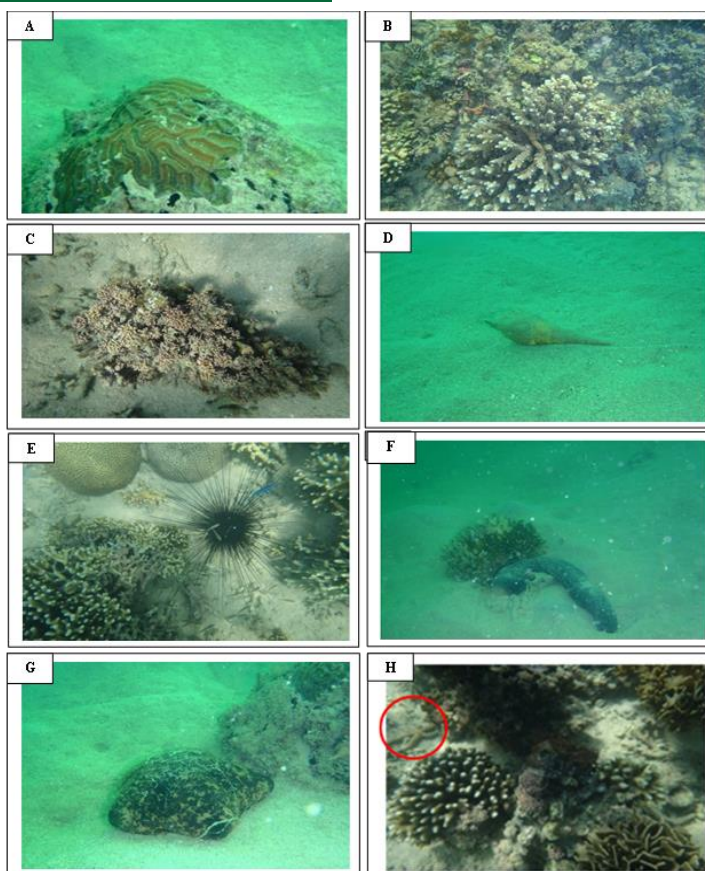


Figure 5: The biodiversity of fauna and flora identified in Ras Issa studied area.

- A)** *Platygyra lamellina sp.* buried at the jetty surface at a depth of 10m (2015), **B)** Different types of dams of *Stylophora pistillata, sp Acropora*, destroyed by high rate of sedimentation (2015), **C)** colonies, coralline alga (2015), **D)** Types of snails (gastropod of mollusks) (2015), **E)** Sea Urchin *Diadema* of echinoderms (2015), **F)** Sea cucumber from the skin of echinoderms (2015), **G)** Echinoderms of the starfish (2015), **H)** Brittle starfish of echinoderms (2015).

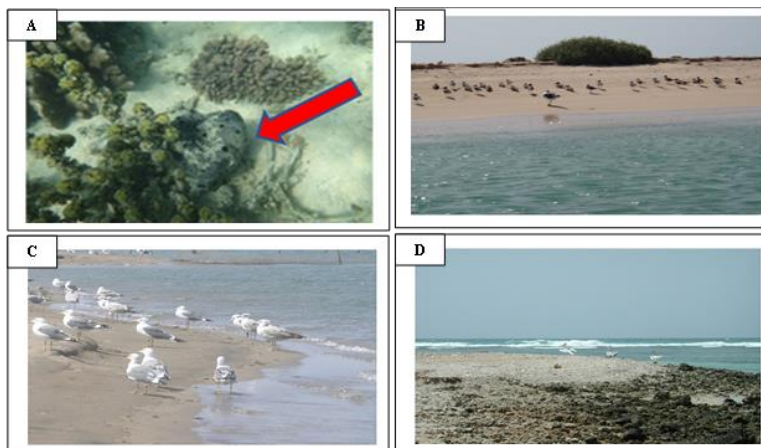


Figure 6: The biodiversity of fauna and flora identified in Ras Issa studied area.

A) sponges and posesities (2015), B) Gatherings of seabirds in Ras Issa201) , C) The Little Black-backed Gull, *Larus fuscus*, recorded at Site 2 in the extreme northwest of the Ras Isa Peninsula2010) , D) Pink-backed Pelican *Pelecanus rufescens* seen at Site 3 northwest of the Ras Isa Peninsula2010) .

Table 5: show Breeds, species, and common name of fishes found in Ras Issa (2015 survey).

| Family | Species | Common name | Family | Species | Common name |
|-----------------------|--|----------------|-----------------------|--|----------------|
| Chaetodontidae | Chaetodon larvatus Chaetodon semilarvatus | Butterfly fish | Chaetodontidae | Chaetodon larvatus Chaetodon semilarvatus | Butterfly fish |
| Haemulidae | Plectorhinchus gaterinus | Sweetlips | Haemulidae | Plectorhinchus gaterinus | Sweetlips |
| Labridae | Cheilinus abudjubbe Gomphosus Caeruleus | Wrasses | Labridae | Cheilinus abudjubbe Gomphosus Caeruleus | Wrasses |
| Lutjanidae | Lutjanus argentimaculatus | Snappers | Lutjanidae | Lutjanus argentimaculatus | Snappers |
| Pomacanthidae | Pomacanthus asfur | Angel fish | Pomacanthidae | Pomacanthus asfur | Angelfish |
| Pomacentridae | Paraglyphidodon melas | Damsel fish | Pomacentridae | Paraglyphidodon melas | Damsel fish |
| Serranidae | Epinephelus Areolatus | Gropers | Serranidae | Epinephelus Areolatus | Gropers |
| Acanthuridae | Acanthurus gahhm | Surgeon fish | Acanthuridae | Acanthurus gahhm | Surgeon fish |
| Gobiidae | Cryptocentrus Caeruleopunctatus | Gobies | Gobiidae | Cryptocentrus Caeruleopunctatus | Gobies |
| Hemiramphidae | Hemiramphus far | Halfbeaks | Hemiramphidae | Hemiramphus far | Halfbeaks |
| Scaridae | Chlorurus sordidus Hippocampus longiceps | Parrot fish | Scaridae | Chlorurus sordidus Hippocampus longiceps | Parrot fish |
| Mullidae | Parupeneus forsskali | Goat fish | Mullidae | Parupeneus forsskali | Goatfish |
| Dasyatidae | Taeniura lumma | Rays | Dasyatidae | Taeniura lumma | Rays |
| Serranidae | Epinephelus malabaricus Epinephelus summana | Gropers | Serranidae | Epinephelus malabaricus Epinephelus summana | Gropers |
| Family | Species | Common name | Family | Species | Common name |
| Chaetodontidae | Chaetodon larvatus Chaetodon semilarvatus | Butterfly fish | Chaetodontidae | Chaetodon larvatus Chaetodon semilarvatus | Butterfly fish |
| Haemulidae | Plectorhinchus gaterinus | Sweetlips | Haemulidae | Plectorhinchus gaterinus | Sweetlips |
| Labridae | Cheilinus abudjubbe Gomphosus Caeruleus | Wrasses | Labridae | Cheilinus abudjubbe Gomphosus Caeruleus | Wrasses |
| Lutjanidae | Lutjanus argentimaculatus | Snappers | Lutjanidae | Lutjanus argentimaculatus | Snappers |
| Pomacanthidae | Pomacanthus asfur | Angel fish | Pomacanthidae | Pomacanthus asfur | Angelfish |
| Pomacentridae | Paraglyphidodon melas | Damsel fish | Pomacentridae | Paraglyphidodon melas | Damsel fish |
| Serranidae | Epinephelus Areolatus | Gropers | Serranidae | Epinephelus Areolatus | Gropers |
| Acanthuridae | Acanthurus gahhm | Surgeon fish | Acanthuridae | Acanthurus gahhm | Surgeon fish |
| Gobiidae | Cryptocentrus Caeruleopunctatus | Gobies | Gobiidae | Cryptocentrus Caeruleopunctatus | Gobies |
| Hemiramphidae | Hemiramphus far | Halfbeaks | Hemiramphidae | Hemiramphus far | Halfbeaks |
| Scaridae | Chlorurus sordidus Hippocampus longiceps | Parrot fish | Scaridae | Chlorurus sordidus Hippocampus longiceps | Parrot fish |
| Mullidae | Parupeneus forsskali | Goat fish | Mullidae | Parupeneus forsskali | Goatfish |
| Dasyatidae | Taeniura lumma | Rays | Dasyatidae | Taeniura lumma | Rays |
| Serranidae | Epinephelus malabaricus Epinephelus summana | Gropers | Serranidae | Epinephelus malabaricus Epinephelus summana | Gropers |

4. FSO_SAFER at Ras Issa and Oil Pollution Risks

The area around the site of FSO_SAFER is rich in biodiversity includes petroleum port for the oil of Safer Oil Field and 428 km pipe line transport crude oil from Ma'rib province to FSO_SAFER. The petroleum station is far 2 km from the shore and 6 km immersed under the sea to the Tank with pumping capability of 7000 barrels/hour. The storage capacity reaches 3,000,000 barrels (SAFER, 2009; SAFER, 2017). It is currently loaded by about 1,140,000 barrels. It is working for 35 year and shelf life is over. Oil sludge are deposited in the bottom, accumulated over the years, which includes concentrated toxic heavy metals such as As, Pb, Co...etc. Safer Company according to official declarations has not performed any maintenance or clean the vessel since 2015. The decrepit tanker and dangerous oil load expect great risk for the life in the Red Sea coastal environment and Ras Issa is the most affected area.

4.1 FSO_SAFER Location

The FSO_SAFER is located in the Yemeni maritime off shore area, 8 km far from Ras Issa (Figure. 1). The site shows the extent of the risks to particular exposed Ras Issa extending along Yemeni coast to the city of Hodeidah, whether if the FSO_SAFER oil load is leaked or explosion.

4.2 Condition of FSO_SAFER and seawater leakage accidents

During July 2020 to the end of 2020, monitoring and follow-up operations of FSO_SAFER is suffered three seawater infiltration incidents into the hull

of the vessel, may results a shipwreck and degradation due to delay maintenance for six years ago, as well as previous poor maintenance.

The vessel has neither been moved since 1987 nor undergone maintenance at dry land ports. Moreover, the hull of the vessel is a single rather than double structure, compare to the structure of modern oil tankers, which is led to increase probability of oil leakage and sinking. The modern model of oil vessel consists of double hull (Fig. 4) make it easy performance maintain to prevent oil or seawater leakage.

Conversely, the hull of FSO_SAFER is of single structure, lack of maintenance, accumulation of oil sludge inside over a time and presence of snail deposits outside the tank, all together expect oil leaks from the vessel. The situation is compounded by more than 35 years of long work as oil storage tank, explaining intrusion of seawater into the ship during the last period.

The leakage was happened in September 2020 as seawater seeps into the ship. Unfortunately, the appicate treatments did not resolve the leaks. The engineering teams are unable to stop the water leaks from one of the pipes due to the rust of the valve and is dilapidated. This is occurred because of intentional neglect and lack of maintenance. The risk will be increased if the vessel is exposed to damage, and led to wide-scale disaster. The water leaks exposed the vessel to sink. Engineering team is facing only one solution to stop the leak of water by closing and block the water inlet and outlet vents, in which 8 vents for water entry and 4 vents are exited, using for cool the engines.

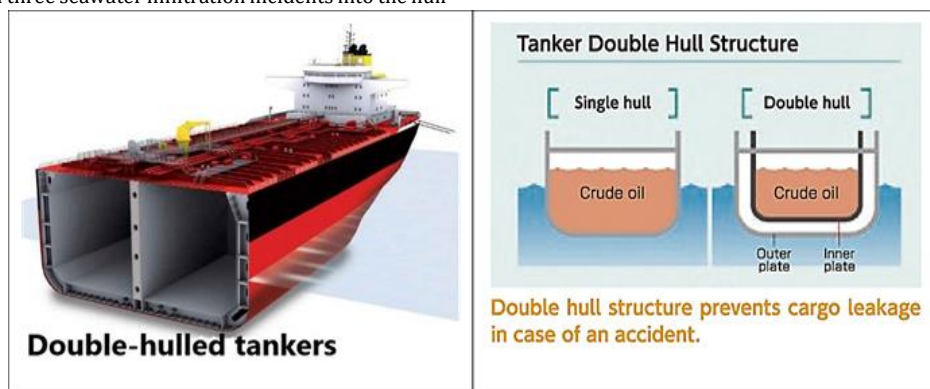


Figure 7: Schematic models shows single and double hulls of oil tank. (https://www.mol.co.jp/en/iroiro_fune_e/ships/02_tanker.html and <https://mfame.guru/double-hulling-ships-market-trends-estimates>)

5. DISCUSSION

5.1 Expected Scenarios

The vessel conditions i.e. no maintenance, oil leakage, large quantities of oil load; are affected the vessel and the expect scenarios of damage are;

1. The vessel could be explode either under attack or as a result of accumulated gases and vapors.
2. Sinking of the ship; decaying ship is on the verge of collapse.
3. The oil leakage and sludge led to damage the ship and interrupt the maintenance work.

Accordingly, it is necessary to take these scenarios in consideration to suggest developed plan to avoid and risk in cooperation with international organizations and Yemeni government.

5.2 Predictable Impacts on Marine Environment and Climate

Exists of oil and high-toxic sludge make significant risks to the Red Sea environments, especially Yemeni coastline. It is also affect the international navigation line and the impact may extend to all countries in the Red Sea (Saudi Arabia, Egypt, Jordan, Sudan, Djibouti, Eritrea, and Yemen). The probable risks may affect the environment and biodiversity and in turn, will reflect on human and agricultural land to cause cancers and skin diseases, death, and destroyed all environments.

Several expectations of environmental impacts of oil leaks comprised two models, the first for oil spill extensions from the FSO_SAFER and the second for distribution of air pollution by FSO_SAFER disaster (Fig. 6)

(after UK Dept. for International Development (DFID)-August 2020

(<https://www.riskaware.co.uk/insight/fso-safer/>) and published by the US Secretary of State.

1st model, predicts the impact of the oil spill path from FSO_SAFER along Yemeni coast, to reach Bab al-Mandab, extending S wards to the Gulf of Aden, and N wards to the cost of Saudi Arabia.

The colors denote effects of oil pollution (Figure. 5): Deep Red = 100%, Light Red = 80%, Deep Orange = 60%, Light Orange = 40%, Very Light Orange = 20%.

2nd model, show expectation extend of air pollution impact from Safer vessel to cover the Yemeni coast and cities around the area i.e. Hajjah, Hodeidah, Rimah, Taiz, Lahij, part of Muhawit and Aden, and extends to the cost of Saudi, Eritrea and Djibouti. The particle size is reaching 2.5 PM.

There is no limit for air pollution and can distribute to wide regions of the world, especially if the ship is exploded and oil load will burn to emit toxic gases. The speed and wind direction have the main role in distribution of aerobic pollution and will affect climate change. Yemen is one of most affected countries (EPA, 2015). Expected pollution impacts upon coasts of the Red Sea will affect the following biodiversity and human activities (international and official reports):

- 185 to 200 coral species are found in the reef of the Red Sea and Gulf of Aden (PERSGA, 2010).
- Mangrove forests are covering the coast of the Red Sea, total of 450-500 km² (PERSGA, 2009).
- Four turtle's species are found in Yemen with green and hawksbill turtles (EPA Yemen, 2019).

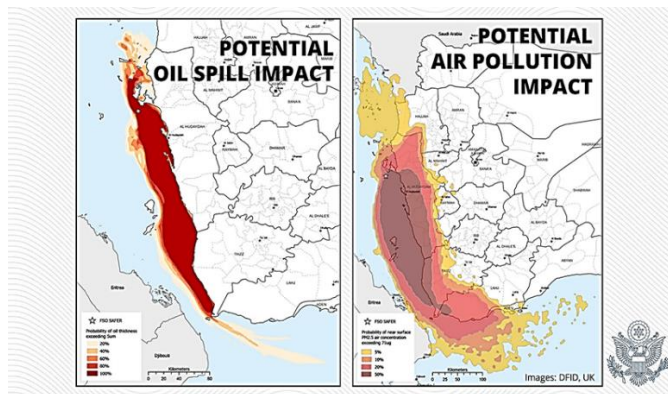


Figure 8: Predictive models of oil pollution and extended effects due to the oil spill from the vessel Safer.

- 343 land and water birds species are reported in Yemen (Yemen Profile 2018), 82 are of coastal and marine species recorded on the red Sea coasts (EPA Yemen, 2004).
- 102 Yemeni islands are reported in the Red Sea (Al-Mehdawy et al. 2022).
- About 40,000 Yemeni fishermen is working in the Red Sea/Gulf of Aden (CSO Yemen, 2011).
- 850,000 ton of fish stockpile is reported in the Yemeni the Red Sea (EPA Yemen, 2005).
- There are 327,000 hectares of agriculture land are recorded in Al-Hodeidah governorate (CSO Yemen, 2011 and MOAI Yemen, 2013), as mostly affected governorate by pollution.

The repercussions of oil leaks can severely damage the natural resources by oil and derivatives or will inhibit the ability of certain organisms to reproduce or reduce the rate of hatching of eggs. The oil slick act to damage the eggs and floating life (sperms) (Turner and Tester, 1997). Moreover, small quantities of oil slick is evaporated to cause air pollution, another quantities are dissolved in water to form oil emulsion, which disrupt the balance of dissolved oxygen and other gases in the water, prevent the suffocate of marine organisms and eliminate the main food sources of plant and other organisms. If the sticky oil spots reaches to the beach sand, it act to kill all marine organisms and fish larvae, and the birds will lose the source of food. Moreover, the stick of oil spots in the bird led it difficult to fly and dead (Freije, 2015).

Crude oil contains toxic organic compounds i.e. polymetallic hydrocarbons (PAHs), transferred to the human body by contaminated fish to pose a health threat from skin diseases and cancers (Furness, 2002). It is seriously implicated for agricultural areas-Tehama plane and adjacent coast, marine fish sector, and international navigate operations will also cease.

Because of war conditions and inability of the United Nations teams to access the vessel, it cannot give clear assessment effects. Generally, Red Sea is subjected to high risks, if FSO-SAFER vessel is damaged. The severe short-term and serious long-term effects are including:

- The black band disease in coral reefs is attributed to petroleum pollution (Haapkyla et al. 2007)
- One liter of spilled oil is covering more than 4000 m² of surface water, prevent gas exchange and dissolve of oxygen in seawater, and affect the gas balance (USOE EPA, 1999).
- Benzopyrin is the most toxic oil compound and leaking is influenced the terrestrial and marine ecosystems, which causing cancer and death of aquatic organisms.
- Many fumes are rising from oil stains transported by wind away to the coastal areas, and the saturated air fumes more than the acceptable limit, will affects the terrestrial and marine ecosystem (Abdel-Shafy and Mansour, 2016).

5.3 Estimated Costs to Remove Environmental Damage If FSO_SAFER Disaster

The value of oil load in FSO_SAFER vessel is not compared to the economic and environmental costs if the tank is collapsed. Estimated costs of the vessel withdraw and sucking oil will not amount to tens of million dollars (<https://news.un.org/ar/story/2022/05/1101442>).

The costs to remove damages may reach billions dollars and not mention

the damage that will persist over decades, which is directly affect the people, environment and all activities as well as the coast of Red Sea environments. It is imperative for all those involved in this issue to consider the material, human and time costs occur if dangerous disaster is not avoided soon.

Consequently, estimate cost to remove damages of oil spill is carrying out depending on many laws and experiences in the study of EIA and estimated costs of removing oil pollution damage in oil fields in Yemen (KECC Yemen, 2016; KECC Yemen, 2014).

Summarize of legal aspects of procedures and compensation for oil pollution of national, international and regional levels was done. Activities of oil industry are accompanied with globally known pollutants. It is follow the standards and controls to minimize pollution and facilitate the process of removal according to legal contracts and conditions in the Yemeni Environmental Law No. 26 of 1995 (EPA Yemen, 1995) and the Law of the Protection of the Marine Environment from Pollution No. 16 of 2004 (Roy, 2004).

If pollution is occurred, the used procedure is; detection of environmental violation or offence by the pollution control officer, written notice to the responsible side of pollution, removal of damage and compensation. Yemeni laws refer to procedures in various articles, c.f. article 76 of the Environment Act No. 26 of 1995, followed many laws in the Arab countries and the world.

5.4 Assessment Mechanisms for Environmental Damage, Removal And Compensation

Two methods are used to estimate the financial costs of oil pollution damage (Al-Taweel, 2012); 1) Standardized assessment of pure environmental damage, 2) Random estimation of compensation.

There are international legal principles of "polluter pays" (The polluter principle pays include compensation for direct damage of the environment, protection expenses for hazardous or special activities (<https://www.unescwa.org/sd-glossary/polluter-pays-principle>). Thus continuous encompassing or periodic contaminated activities and other areas covered by the propellant is principally applied in several States (Ali, 2014):

- I. The scope of principle apply polluter-pays is extended to the expenses of administrative procedures; expenses control, measurement and analysis of pollution done by administrative interests, which are charged to the polluter according to the polluter-pays principle.
- II. The polluter-pays principle extends to residual damages in the sense if the polluter commits to pay certain instalments for the sea pollution. It can be pursued or rather charged with other additional expenses when real collateral damage occurs, even if is not taken into account.
- III. Expanding of the polluter-pays principle to the pollution cases resulted by from accidents; are included in 1998 by the Organization for Economic Cooperation and Development (OECD, 2006). This procedure aims to reduce accidents and the burdens of the public budget relative to the categories of pollution accidents and in return the facility owner is bearing the burdens. It also aims to motivate the facilities owners to take necessary precautions to avoid accidents.
- IV. Expanding of the polluter-pays principle to the area of illicit pollution: If a polluter exceeds the permissible pollution threshold and causes harm to others, compensation and fines are required.

V. The expansion of the polluter-pays principle for transboundary pollution.

The kind of compensation is not easy and can be replaced by monetary compensation. Thus, many laws specify exclusive polluted damage areas of compensation and reported in the content and result, which are almost the same. For example, Yemeni Environmental Protection Act and Marine Environment Protection against Pollution Act set out the areas of compensation of environmental pollution, c.f. Article 79 of the Environment Act (26) (1995).

The American Oil Pollution Act (1990) addresses the areas of compensation (Article No. "1002") (US, Oil Pollution Act of 1990). These encompass wide areas, including:

- The damage of natural resources caused by injury and destruction, and the loss of any possibility of utilizing such resources
- Personal property and economic losses resulting from such damage, whether by damage to real or personal property.

The liability for marine oil pollution incidents, the International Convention on Civil Liability for Oil Pollution Damage (1969), and amended protocol (1992) (UN, 2003), sought to ensure that are affected by ship accidents and resulted oil pollution to receive appropriate compensation.

5.5 Maintenance of the FSO_SAFER

Actually, all vents are welded and blocked until the water stopped. The ship's engineers can repair the valve and the leaking tube, which are not

repaired and water leaks were sucked out by a suction pump and drainage to the sea (Figure. 6). In fact, all valves and tubes are mostly rickety and rust. The repairing process is temporary and didn't do much and may have increased the risks or more. The outlet water of vessel refrigerators and engines has stopped moving due to block of openings. This has more than one implication;

Firstly, the vessel's engines are interrupted that delay to transfer if the international community is decided. The ship must be maintained to enable water to circulate and exit by the blocked vents.

Secondly, the stop of circulation of cooling water led to increase temperature of many equipment and rise the temperature of the stored oil that increase the risks of disaster of explosion.

Thirdly, the new water leak inside the vessel is likely to occur due to damage of the valves, pipes and other equipment, and this is actually happened as the third water leak.

Fourthly, large quantities of withdrawal/disposal leaks water to the sea without treatment, led to contaminate inside the vessel, is likely of risk, affecting the biodiversity.

Fifthly, FSO_SAFER satellite images show leaks from the vessel, because of oil spill from the vessel (Satellite image of FSO_SAFER on September 14, 2020 published on Planet site, <https://www.planet.com>). This date coincides with the time of the second water leaks in the ship.

Analysis of satellite image shows no oil spill from the ship, rather the process of throw out leaked water to the sea. The graphic illustrates the image by determining the divisions of the ship, shows the location of the oil tanks and engines and the location of the substances that leaked to the sea.

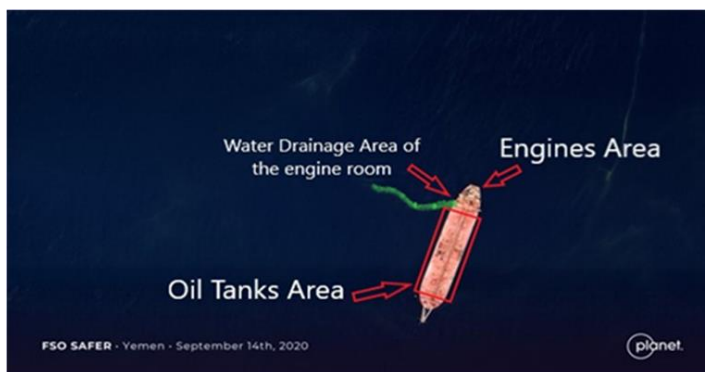


Figure 9: Schematic chart shows the subdivisions of the Safer vessel and the site of leakage and discharged to the sea (green color) (September 2020).

5.6 Estimated Cost to Remove Damage of Biodiversity Around the FSO_SAFER Disaster

Many studies c.f. have dealt with the issue to calculate the cost of removal damage of oil spills in offshore areas Juan (2019). Estimated cost is ranged from \$300,000 to clean a ton of oil in large-scale areas to \$29,000 of clean a ton in near-shore accidents (Otekenari and Maclean, 2021). The International Oil Pollution Compensation Fund (IOPCF) suggests to clean a ton of spilled oil cost need \$514,437 compensate for environmental damage from fisheries, tourism and agriculture only (Fig. 7). Environmental sensitivity of bio and social diversity are clear present in the area. The calculations related to manage the project, equipment and materials required to eliminate damage rely on international laws. In this framework, decisions of Yemeni Ministry of Transport No. 77 of 2010, Marine Environment Protection against Pollution Act No. 16 of 2004 and Environmental Protection Act No. 26 of 1995 are applicable, to obligate for protection against environmental damage and adequate compensation (MOT Yemen, 2010; Roy, 2004; EPA Yemen, 1995; Etkin, 2004).

1992 Protocol is amending the International Convention on Civil Liability for Damage of Marine Oil Pollution of 1969 (UN 2003), are relied to calculate the cost of remove damages. Other factors c.f. rate and amount of spillage, weather and sea conditions, time of the year and the effectiveness of clean-up can be crucial in determine overall cost of an incident (White and Molloy, 2003).

Depend on the amount of crude oil in the Safer vessel (1,140,000 barrels), transactions in the annex in Table (6), by calculate environmental and social transactions, estimated fines on quantity and calculating the management rates of cleaning operations and administrative and technical work of removal cost of environmental damage c.f. coral reefs, mangrove forests, ...etc., in Yemeni Red Sea region; the cost of removing environmental damage will be \$26.1 billion (Figure.8). (env. damage \$15,9 B, clean up implementation \$5,45 B, technical work \$2,41 B, and contingency \$1,7 B).

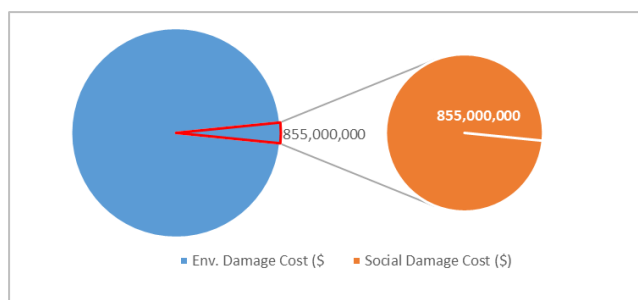


Figure 10: The estimated cost of removing the environmental and social damage in the Red Sea resulted from FSO_SAFER disaster.

Table 6: Calculating Environmental and Social Transactions And Estimated Fines on Quantity and Calculating the Rates of Management of Cleaning Operations And Administrative and Technical Work of The Cost of Removing Environmental Damage from FSO_SAFER

| | Oil Content in FSO (B) | Total Oil Spill (L) | Compensation and Damage Cost | | | | Clean up Implementation | | | | Management and Technical Work | | | Subtotal Cost(\$) | Contingency 7% | Total Cost (\$) |
|---|------------------------|---------------------|-------------------------------|----------------------|------------------------|----------------|----------------------------|---------------------------------------|-------------------------------|---------------|-------------------------------|----------------------|----------------|-------------------|----------------|-----------------|
| | | | Compensation for spill (\$/L) | Env. Damage Cost(\$) | Social Damage Cost(\$) | Total C&D Cost | Soil Cleanup Cost (\$) 20% | Solid Waste Collection and Storage 3% | Facilities Rehabilitation 10% | Total CI Cost | Project Management 8% | Technical Support 3% | Total MTW Cost | | | |
| 1 | 1,140,000 | 228000 | 570,000,000 | 15,960,000,000 | 855,000,000 | 16,530,000,000 | 3,306,000,000, | 495,900,000 | 1,653,000,000 | 5,454,900,000 | 1,758,792,000, | 659,547,000 | 2,418,339,000, | 24,403,239,000 | 1,708,226,730, | 26,111,465,730 |
| | | | | | | | | | | | | | | | 26,111,465,730 | |

Notes: on Resolution of the Minister of Transport No. (77) for the year 2010 Concerning the calculation of environmental compensation for marine oil pollution incidents system

- Env. Factor = 28 (Areas of algae and seaweed, Tidal flats and salt marshes, Corals, Mangrove trees areas, Open marine waters, Ports and offshore platforms and navigational channels, Industrial and economic installations, Fishing ports and fish landing zones, Facilities and beaches for recreation and tourism, Fisheries and marine mammals, Sandy and unused beaches, Shallow water near beaches, Rocky beaches and shellfish, Sheltered bays, small bays and water inlets, Fish farms and areas of marine aquaculture and hatchery, Beaches where turtles or seabirds nest.
- Social Factor = 1.5
- Oil Spill = 2.5 \$/L

6. SUGGESTION FOR MITIGATE DISASTER OF SFO_SAFER VESSEL

It is suggested that all the following are used to mitigate the damage and environmental pollution impact of the area; states, civil society organizations, international environmental organizations and wildlife and marine organizations must cooperate to compel the United Nations and the international community to intervene promptly, effectively, pull the vessel to dry ports and offload oil to avoid any risks, and not to keep the ship in any particular party.

Cooperation with international and national experts is suggested to assess the damages, towed and repaired, waste must be treated and population damage and any biodiversity must be compensated.

The work should not be limited to unloading the vessel load but also to clean the vessel and taking advantage of oil that may be produced as a result of processing operations. It includes impacts of environmental of all unloading operations, withdrawal, maintain the vessel and disposal of sludge.

7. CONCLUSION

The Ras Issa area in Hodeidah Governorate suffers from environmental pressures, both at the level of changing seawater characteristics and degradation of biodiversity, especially coral reefs, as well as population growth accompanied by lack of services and infrastructure. In addition to weak and scarce information about the area since 2015 and the barring of researchers or even United Nations teams from entering Ras Issa area due to hostile conditions, all these will also have disastrous effects in the event of any oil spill or explosion of the FSO_SAFER in the area that is considered the most affected event for any pollution.

The situation of the "FSO_SAFER" is deteriorating both for the hull level and the equipment level, which has

stopped working and was maintained for years. The long operation period and the value of the oil load on board are not comparable to the economic and environmental costs if the tank is collapsed. Estimates of the cost of the ship withdrawing and suctioning the oil will be beyond tens of millions of dollars, while the costs of the expected removing damages can reach 26.9 billion dollars. This does not take in account the damage that continue for decades and will directly affect humans, the environment, all activities and areas of the Yemeni Red Sea coast in particular. This makes it imperative that all those involved in this issue consider the material, human and time

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