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تم استلام الورقة بتاريخ:6/ 1/2024م وتم نشرها على الموقع بتاريخ:31/ 1/2024م

Risk Assessment of Oil Spill from the Al-Bouri Platform on the Western Libyan Coast

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Abstract

Risk assessment, one of the essential stages of risk management, involves the definition of the specific impacts of exposed objects and the probability of the occurrence of negative effects. A scientific and accurate risk assessment in terms of oil spills for prevention and readiness can help to better manage emergency plans and minimize economic damage. The main objective of this paper is to assess the risk of oil spills on the Western Libyan coast and determine the high-risk areas on the coast for response planning.

The Environmental Sensitivity Index Tool was used as a methodology to summarize the potential sensitivity of the Western Libyan coastline, which was divided into various sectors Based on the National Oceanic and Atmospheric Administration's (NOAA) sensitivity classification. In addition, an oil spill mathematical SL-ROSS model was used to predict the trajectory and fate of oil spills on the coast to assess the risks associated with oil spills in this area and to highlight the vulnerable areas to be a support tool for decision-making in future emergencies. Also, this paper presents a carried out Sensitivity Map for the Western Libyan Coastlines using the Geographic Information System (GIS). The findings of the oil risk assessment show that a great length of the shoreline (146.04 km, or around 40% of the Libyan coast) in the study area faces a high oil spill risk level, while 129.25 km of the shoreline (35% of the Libyan coast) faces a medium oil risk level. In addition, the shoreline of 90.18 km faces a low oil spill risk level, representing 25% of the whole shoreline. The study's findings aid decision-makers in

تم استلام الورقة بتاريخ:6/ 1/2024م وتم نشرها على الموقع بتاريخ:31/ 1/2024م

devising preventive measures in the event of a spill near the Libyan coastline.
Keywords: Oil spill risk assessment, Impact oil spill, Environmental Sensitivity Index, The western Libyan coast.

تقييم مخاطر التسرب النفطي من منصة البوري على الساحل الليبي الغربي

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الملخص

يعتبر تقييم المخاطر من أحد أهم المراحل الأســـاســـية لإدارة المخاطر لتحديد التأثيرات المحددة للأشياء المعرضـة أو المحتملة الحدوث التي تسبب التأثيرات السلبية. إن التقييم العلمي والدقيق لمخاطر المتعلقة بالانسـكابات النفطية مهمة جدا وذلك للوقاية والاســتعداد والتأهب الذي أن يســاعد في إدارة خطط الطوارئ بشــكل أفضــل وتقليل الأضــرار الاقتصــادية عند حدوثها. الهدف الرئيســي من هذه الورقة هو تقييم المخاطر المتعلقة بإنســكابات النفط على الســاحل الغربي الليبي وتحديد المناطق عالية الخطورة على الساحل.

تم استخدام أداة مؤشر الحساسية البيئية (ESI) كمنهجية لتحديد وتصـنيف الحساسية البيئية للسـاحل الغربي الليبي والذي تم تقسيمه إلى 16منطقة في هذه الدراسـة. حيث تم هذا التصــنيف وفقا إلى مؤشــر الحســاســية البيئية الحســاســية التابع للإدارة الوطنية للمحيطات والغلاف الجوي (NOAA). بالإضـافة إلى ذلك، تم اسـتخدام نموذج الخاص بالتسرب النفطي(SL-ROSS) وذلك للتنبؤ بمسار و مصير الانسكابات النفطية على الســـاحل الليبي لتقييم المخاطر المرتبطة بهذه الانســكابات في منطقة الدراســة لغرض

تم استلام الورقة بتاريخ:6/ 1/2024م وتم نشرها على الموقع بتاريخ:31/ 1/2024م

تسليط الضوء على المناطق المعرضة للخطر ولتكون أداة دعم لاتخاذ القرارات في حالات الطوارئ المستقبلية.كما تعرض هذه الورقة خريطة حساسية للساحل الغربي الليبي التي تم إنشائها باستخدام نظام المعلومات الجغرافية (GIS). حيث أظهرت نتائج هذه الدراسة أن الخط الساحلي (146.04 كم أو حوالي 40٪ من الساحل الليبي) في منطقة الدراسة يواجه مستوى مرتفع من خطر تسرب النفط. في حين أن 129.25 كم من الخط الساحلي (35٪ من الساحل الليبي) يواجه مستوى مخاطرة نفطية متوسطة. بالإضافة إلى ذلك، يواجه الخط الساحلي الذي يبلغ طوله 90.18 كيلومترًا مستوى منخفض من خطر التسرب النفطي وهو ما يمثل 25% من الخط الساحلي بأكمله. وتساعد نتائج هذه الدراسة صناع القرار في وضع التدابير الوقائية في حالة حدوث تسرب بالقرب من الساحل الليبي.

الكلمات المفتاحية: تقييم مخاطر التسرب النفطي، تأثير التسرب النفطي، مؤشر الحساسية البيئية، الساحل الغربي الليبي.

1. INTRODUCTION

One of the most dangerous contaminants in the marine and coastal environment is an oil spill. In the last several decades the regional coastal ocean has been impacted by many catastrophic oil spills: the Aegean Sea, 1992; Prestige 2002; and most recently, the Deepwater Horizon in 2010 oil spill in the Gulf of Mexico, discharging approximately 492,000 to 627,000 tons of oil (Corn, 2010; Hagerty, 2010;Keramea et al, 2021). According to ITOPF Statistics 2020, over 80% of the incidents recorded since 1970 were small spills (<7 tons) which has shown that major spill incidents have been fewer in number, but it still usually remains that minor spills happen daily at ship terminals, near onshore refineries, and other similar facilities (ITOPF, 2020).Unfortunately, data for accidental spills are often incomplete and highlight the need for improved oil spill detection and monitoring (Keramea et al, 2021).

Libya is a member of the Organization of the Petroleum Exporting Countries and the holder of Africa’s largest proved crude oil reserves and the fifth-largest holder of Africa’s proved natural gas reserves. (U.S. Energy Information Administration, 2020). Moreover, Libya has three offshore platforms for oil production in

تم استلام الورقة بتاريخ:6/ 1/2024م وتم نشرها على الموقع بتاريخ:31/ 1/2024م

front of the western Libyan coastline (Gulf of Gabes) as shown in fig. (1). The Bouri oil reservoir is considered to be the biggest of its kind in the Mediterranean region It has 4.5 billion barrels of proven crude oil reserves and 3.5 tcf of natural gas (EGYPT OIL- GAS 2021).

as well as intensive oil and gas industry activity along the western Libyan coastline from Zawiya oil refining port, Mellitah oil terminal and the existing offshore platforms located in front of coastal As a result, these levels of oil activity on the Libyan coastline mean that there is a genuine threat to the marine and coastal environment from oil spill, including the attendance and diversity of the marine environment in this region, which is one of the most important areas threatened by an oil spill (UNEP/MAP,2020).

However, oil spill contingency plans have not been attempted yet in Libya. Therefore, there has been no coordinated response to oil accidents in ports or on oil platforms. For instance, the oil spilled from the Farwa oil platform (FPSO) on October 8th, 2021.This accident forced the Environment General Authority into making arrangements to produce a national contingency plan in collaboration with relevant organizations such as REMPEC (The Regional Marine Pollution Emergency Response Centre) (ITOPF, 2021). The National Oil Corporation (NOC) announced that the oil slick was controlled and treated, meaning it would not have a negative impact on Libya’s beaches. However, analysis of satellite imagery suggests this may not be the case as what appears to be oil slicks can be observed near the Farwa FSPO vessel. In the meantime, these slicks appear to be tracking towards the beaches between Sabratah and Zuwara on the Libyan coast, where they are already impacting the marine environment (CEOBS, 2021).

The lack of comprehensive studies of oil spill impacts on marine environments in some specific areas of the southern Mediterranean, particularly in Libya, and the insufficient capacity and limited resources of regional authorities (regional centres designed to address the problem) to implement an adequate response to oil spilling risk.

Risk assessment, one of the essential stages of risk management, involves the definition of specific impacts of exposed objects and the probability of the occurrence of negative effects (ISO, 2009). A

تم استلام الورقة بتاريخ:6/ 1/2024م وتم نشرها على الموقع بتاريخ:31/ 1/2024م

scientific and accurate risk assessment in terms of oil spills for prevention and readiness can help to better manage emergency plans and minimize economic damage (Lan et al., 2015; Nelson et al., 2015). An analysis of risk can contribute to the mitigation of the effects of oil spills (Lehr et al., 2002; Liu et al., 2015). In addition, assessments of oil slick risk may be used to support the formulation of emergency plans and the identification of mitigation policies (Canu et al., 2015; Yu et al., 2018).

As a result, the main objective of this paper is to risk assessment of oil spills in the Western Libyan Coast and determine the high-risk areas on the Western Libyan coast for response planning

2. Model Description and Methodology

2.1 Study area

The scope of this study is to risk assessment of oil spills on the Western Libyan Coast from the Abu Kamash region with the Tunisian border to Tripoli City in northwestern Libya as shown in Figure (1)which lies between 33° 10' 00'' N, 11° 33' 43'' E and 32° 47' 26'' N, 13° 49' 28'' E with a Coastline of the total length of 365 km. This area has the largest populated densely in Libya (Badi et al, 2018, Bureau of Statistics and Census Liby, 2021) Moreover, it has a Marine Protected Area (Farwa Island) (IUCN MedPan, 2021), which is considered the most important of habitats with the highest biodiversity. It is used as nesting grounds for turtles on the Libyan coastline and feeding places for migrant birds. It is also characterized by the existence of many endangered species (Etayeb et al., 2012. SPA/RAC_2016). Furthermore, this area includes Sabratha city, which is the biggest archaeological site as pronounced by the UNESCO World Heritage Site in 1982 (UNESCO, 2021), This area is characterized by a wide continental shelf that extends from the Gulf of Gabes in Tunisia to the Gulf of Sirte, making this area the best fishing region in the Mediterranean. It includes various types of coasts, such as coastal salt marshes, rocky shores, and sandy beaches.

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Figure (1). Locations of Al-Bouri and Al-Jurf fields for oil production in the Continental Shelf, the Mediterranean Sea (Joint Oil, 2021)

2.2 Identification of High Risk Areas at an Oil Spill

A risk is defined as a situation that can cause potential harm to the environment. The structure of an oil spill risk assessment, as shown in Figure (2), is based on: (1) A classification of the coastal areas of high sensitivity to oil spills (Frazão Santos et al., 2013; PIECA-OGP, 2013), and (2) an oil spill simulation database where the oil spill is more likely to occur (Azevedo et al., 2017). The essential objective of this paper is the oil risk assessment, which is to identify the areas of high risk and take measures to reduce the environmental consequences of the spill. This goal is best achieved if the location of sensitive resources and potential oil spill deposition areas are identified in advance, streamlining the establishment of protection priorities and clean-up strategy selection.

The coastal oil spill risk assessment proposed is based on two main components: the environmental sensitivity index was used as the methodology (NOAA, 2002) to produce environmental sensitivity maps, which were represented (Consequences); and the oil spill trajectories database to produce hazard maps, which were represented (Probability) by the licensed and validated SL-ROSS oil spill model. For the framework of this paper, first, the coastal segments are identified to one of four sensitivity levels: very high sensitivity (ESI 9), high sensitivity (ESI 6B to ESI 7), medium sensitivity (ESI 3 to ESI 5B), and low sensitivity (ESI 1 to ESI 2). These levels combined several types of sensitivities covering large scale of maps to show the most important coastal resource features in different colors to produce an ESI atlas of Libya (study area) as a part of the oil spill contingency plan.

Second, the shoreline hazard oil spill (risk) maps are evaluated based on an analysis of oil spill simulations, accounting for annual variability of winds, waves, and surface water current from August 2019 to July 2020. Twenty four scenarios are discussed; 12 regular and 12 worst cases for an oil spill on Al-Bouri offshore platform using the SL-ROSS oil spill model. To make the hazard map clearer, the oil risk index categories were divided into three groups: high oil risk, medium oil risk, and low oil risk. Third, the combination of sensitivity and oil spill risk forms an oil spill risk assessment identifying high-risk areas. This is an essential step in oil pollution preparedness and response that assists responders in preparing the equipment required to reduce potential oil spill risk in a coastal area (Wynja et al., 2015).

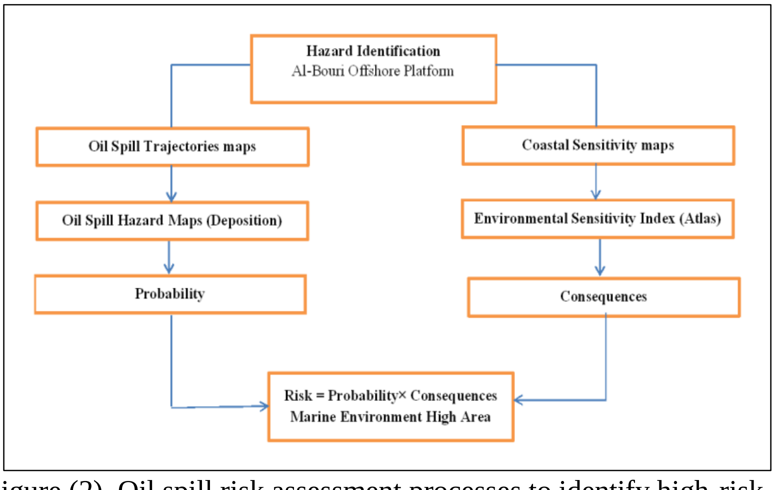

Figure (2). Oil spill risk assessment processes to identify high-risk areas (PIECA- OGP, 2013).

3. Results and Discussion

3.1 Coastal Sensitivity Index Area

The ESI maps were developed to describe shoreline conditions, which serve as part of the shoreline assessment process in oil spill events and contribute to the development of the response. In this

تم استلام الورقة بتاريخ:6/ 2024/1م وتم نشرها على الموقع بتاريخ:31/ 2024/1م

study, the ESI map was used to help provide an oil spill contingency plan (OSCP) in order to provide planners with all the information needed about all coastal segments to develop response strategies for sensitive coasts and the type of equipment to use (Guidi et al., 2015). Thus, these maps help to identify the locations with the highest oil risk in the coastal area (Rustandi et al.,2020b). In addition, the sensitivity index maps can be used as a support tool to develop policies for marine pollution. The maps developed contain three basic types of information: shoreline type, biological resources, and human-use resources. They also include high-resolution environmental sensitivity data, such as shoreline sensitivity and coastal resources/habitats. The coastal sensitivity index consists of four levels, each having varying levels of sensitivity to oil spills; very high, high, medium, and low.

3.2 Very High Sensitivity Coast (ESI 9)

Very high sensitivity index segments of the shore are of several types, including different biological resources and socio-economic activities (Table 1).The highest areas of shoreline sensitivity on the Libyan coast (study area) are classified as ESI 9, which includes the most productive and high biodiversity section of the coastal area because it contains the most environmentally important features on the Libyan coast: turtle nesting areas, migratory bird feeding area, and wetlands.

Table (1). Summary of very high sensitivity shoreline segments of ESI Map.

Category no.	Shoreline segment	Biological index	Socio-economic index	Coast description
ESI 9	Abu Kamash	Wetland (Sabkha)- Sea turtle nesting area- Migratory birdsfeeding area	Historical sites Salt industrySwimming sites Fishing sites	Vegetated low Banks
ESI 9	Al Garaboly	Sea turtle nesting area- Birds feeding area	Swimming sites Fishing sites National Park-	Vegetated low Banks

The ESI 9 shoreline type predominates on the two coasts: Abu Kamash and the eastern part of Al Garaboly shoreline. The high sensitivity to oil spills is due to the generally low wave energy and persistence of oil.

تم استلام الورقة بتاريخ:6/ 1/2024م وتم نشرها على الموقع بتاريخ:31/ 1/2024م

3.3 High Sensitivity Coast (ESI 6B to ESI 7)

The high sensitivity segments in this category are ESI 7 (Table 2).

Table (2). Summary of high sensitivity shoreline segments of ESI map.

Category no.	Shoreline segment	Biological index	Socio-economic index	Coast description
ESI 6B	Abu Kamash	Shoreline species	Abu Kamash Fishing Port	Riprap beach
ESI 6B	Zuwara	Shoreline species	Zuwara Port Fishing Port	Riprap beach
ESI 6B	Mellitah	Shoreline species	Mellitah Port	Riprap beach
ESI 6B	Sabratah	Shoreline species	Zuagha Fish Port Fishing sites	Riprap beach
ESI 6B	Surman	Shoreline species	Surman Fishing Port	Riprap beach
ESI 6B	Zawiya	Shoreline species	Electric Power Plant- Desalination Plant - Zawiya Port- Deela Fishing Port	Riprap beach
ESI 6B	Janzour	Shoreline species	Tripoli West Electric Plant - Sidi Bilal fishing Port - Palm City Guesthouse	Riprap beach
ESI 6B	Gargarish	Shoreline species	Al Qasria Fishing Port- Swimming sites	Riprap beach
ESI 6B	Hai Al Andalus	Shoreline species	Marina Sheraton Hotel	Riprap beach
ESI 6B	Tripoli Centre	Shoreline species	Tripoli Port- Navy base- Dhat Al Emad Complex	Riprap beach
ESI 6B	Souq Al Jumaa	Shoreline species	Fishing Port	Riprap beach
ESI 6B	Tajura	Shoreline species	Hamidia Fishing Port	Riprap beach
ESI 6B	Ghott-Eroman	Shoreline species	Shajara Fishing Port	Riprap beach
ESI 6B	Al Garaboly	Shoreline species	Al Garaboly fishing port	Riprapbeach
ESI 7	Al Garaboly	Intertidal species	Swimming sites	Exposed tidalflats
ESI 7	Tripoli Center	Intertidal species	Dhat Al Emad Complex (AinAzargha)-Swimming sites	Exposed tidalflats
ESI 7	Hai Al Andalus	Intertidal species	Swimming sites Al Qasria Fishing Port	Exposed tidalflats
ESI 7	Sabratah	Intertidal species	Fishing Port- Archaeological sites	Exposed tidalflats

Consisting of exposed tidal flats on the center of Tripoli, Hai Al Andalus, and Sabratah coasts, and are thought to be rich in species.

Oil deposited on these flats may remain for a long time. The riprap beaches (ESI 6 B) are man-made walls or blocks of rock or concrete for shore protection and have a moderate to high abundance of species. Oil may penetrate deeply and adhere to rough surfaces, therefore, the biological resources would be damaged by the oil spill. The probability and frequency of a hazard due to an oil spill are high because most riprap beaches are built near ports and coastal socio-economic sites. This type of shore exists on most segments of the Libyan coast. Moreover, this area contains vulnerable resources, such as summer resorts and ports.

3.4 Medium Sensitivity Coast (ESI 3 to ESI 5B)

The medium sensitivity classes assigned to the rankings ESI3 to ESI5 (Table 3) are concentrated on Abu Kamash, Zuwara, Sabratah, and Al Garaboly coasts. The ESI A3 shoreline sensitivity level represents fine to medium sandy beaches that are common on the eastern coast of Tripoli in Abu Kamash, Zuwara, Sabratah, and Al Garaboly, where waves and currents are not as strong. Oil persistence could be short-term before being removed by wave action. The coastal biodiversity, such as migratory turtles and feeding seabirds, could be under oil spill risk. The mixed sand and gravel beaches of ESI 5 are common in Zuwara, Siahia, and Gargarish and have medium-to-high permeability to oil and usually low biological productivity.

Table (3). Summary of medium sensitivity shoreline segments of ESI map.

Category no.	Shoreline segment	Biological index	Socioeconomic index	Coast description
ESI 3A	Abu Kamash	Sea turtle nesting area- Migratory birds feeding area	Company of Chemical Industry - Swimming sites	Fine to Medium Sandy Beaches
ESI 3A	Zuwara	Sea turtle nesting area- Migratory birds feeding area	Swimming sites- Salt industry- Desalination Plant	Fine to Medium Sandy Beaches
ESI 3A	Sabratah	Shoreline species	Summer resorts- Swimming sites	Fine to Medium Sandy Beaches
ESI 3A	Zawiya	Shoreline species	Swimming sites	Fine to Medium Sandy Beaches

تم استلام الورقة بتاريخ:6/ 2024/1م وتم نشرها على الموقع بتاريخ:31/ 2024/1م

ESI 3A	Janzour	Shoreline species	Swimming sites	Fine to Medium Sandy Beaches
ESI 3A	Tripoli Center	Shoreline species	Summer resorts-Swimming sites	Fine to Medium Sandy Beaches
ESI 3A	Tajura	Shoreline species	Summer resorts-Swimming sites	Fine to Medium Sandy Beaches
ESI 3A	Al Garaboly	Sea turtle nesting area-birds feeding area	Summer resorts-Swimming sites-National Park	Fine to Medium Sandy Beaches
ESI 5	Zuwara	Shoreline species	Swimming sites	Mixed sand and gravel beaches
ESI 5	Mellitah	Shoreline species	Mellitah Oil & Gas-Swimming sites	Mixed sand and gravel beaches
ESI 5	Sabratah	Shoreline species	Swimming sites-Archaeological site of Sabratah	Mixed sand and gravel beaches
ESI 5	Surman	Shoreline species	Swimming sites	Mixed sand and gravel beaches
ESI 5	Zawiya	Shoreline species	Swimming sites	Mixed sand and gravel beaches
ESI 5	Janzour	Shoreline species	Summer resorts-Swimming sites	Mixed sand and gravel beaches
ESI 5	Siahia	Shoreline species	Summer resorts-Swimming sites	Mixed sand and gravel beaches
ESI 5	Gargarish	Shoreline species	Swimming sites	Mixed sand and gravel beaches
ESI 5	Hai Al Andalus	Shoreline species	Summer resorts-Swimming sites	Mixed sand and gravel beaches
ESI 5	Tripoli center	Shoreline species	Tripoli Port	Mixed sand and gravel beaches
ESI 5	Souq Al Jumaa	Shoreline species	Summer resorts-Swimming sites	Mixed sand and gravel beaches
ESI 5	Tajura	Shoreline species	Summer resorts-Swimming sites	Mixed sand and gravel beaches
ESI 5	Ghott-Eroman	Shoreline species	Swimming sites	Mixed sand and gravel beaches
ESI 5	Al Garaboly	Shoreline species	Swimming sites-National Park	Mixed sand and gravel beaches

3.5 Low Sensitivity Coast (ESI 1 to ESI 2)

Low sensitivity shorelines are classified as ESI 1 and ESI 2 (Table 4). These areas are predominantly along the eastern coast of Tripoli, from Sabratah City to the western coast of Ghott- Eroman City, and consist of exposed rocky shores, exposed man-made structures, and exposed wave-cut platforms with rocky headland. The ESI 2A

تم استلام الورقة بتاريخ:6/ 2024/1م وتم نشرها على الموقع بتاريخ:31/ 2024/1م

represents exposed wave-cut platforms, which are the narrow flat areas often found at the base of a sea cliff. In the event of an oil spill, the oil can remain on the flats and take a long time to be removed from sheltered areas. Thus, rocky species and habitats might be damaged. The ESI 1B refers to exposed, man-made structures where species' abundance and diversity are low. These areas are located around factories and ports and are exposed to high wave energy, which pushes oil offshore as waves are reflected off sloping or vertical faces. Finally, ESI 1A exposed rocky shores are common along the Libyan shoreline, with a total length of 50.57 km. This type of shore is subjected to high wave energy, is self-cleaning of oil, and contains few species

Table (4). Summary low sensitivity shoreline segments of ESI Map.

Category no.	Shoreline segment	Biological index	Socio-economic index	Coast description
ESI 1A	Mellitah	Rocky shores species	Mellitah Oil & Gas	Exposed rocky shores
ESI 1A	Sabratah	Rocky shores species	Swimming sites	Exposed rocky shores
ESI 1A	Surman	Rocky shores species	Swimming sites-fishing port	Exposed rocky shores
ESI 1A	Zawiya	Rocky shores species	Zawiya Oil Refinery Company - Desalination Plant - Electric Power Plant- Swimming sites	Exposed rocky shores
ESI 1A	Al Maya	Rocky shores species	Swimming sites-Marine Academy	Exposed rocky Shores
ESI 1A	Janzour	Rocky shores species	Navy college-Swimming sites-Summer resorts	Exposed rocky Shores
ESI 1A	Siahia	Rocky shores species	Swimming sites-Summer resorts	Exposed rocky Shores
ESI 1A	Tajura	Rocky shores species	Swimming sites	Exposed rocky Shores
ESI 1A	Ghott-Eroman	Rocky shores species	Swimming sites	Exposed rocky Shores
ESI 1A	Al Garaboly	Rocky shores species	Swimming sites-Lighthouse AlGaraboly	Exposed rocky Shores
ESI 1B	Abu Kamash	Man-made structure species	Terminal of Chemical Industry-Fishing port	Exposed man-made structure

ESI 1B	Zuwara	Man-made structure species	Zuwara Port	Exposed man-made structure
ESI 1B	Mellitah	Man-made structure species	Mellitah Terminal- Mellitah Port	Exposed man-made structure
ESI 1B	Sabratah	Man-made structure species	Fishing port	Exposed man-made structure
ESI 1B	Surman	Man-made structure species	Surman Fishing port	Exposed man-made structure
ESI 1B	Zawiya	Man-made structure species	Zawiya Port- Deela Fishing Port	Exposed man-made structure
ESI 1B	Janzour	Man-made structure species	Tripoli West Electric Plant- Sidi Bilal Fishing Port	Exposed man-made structure
ESI 1B	Gargarish	Man-made structure species	Al Qasria Fishing Port	Exposed man-made structure
ESI 1B	Hai Al Andalus	Man-made structure species	Marina Sheraton Hotel	Exposed man-made structure
ESI 1B	Tripoli center	Man-made structure species	Tripoli Port-Navy base	Exposed man-made structure
ESI 1B	Souq Al Jumaa	Man-made structure species	Fishing Port	Exposed man-made structure
ESI 1B	Tajura	Man-made structure species	Al Hamidia Fishing Port	Exposed man-made structure
ESI 1B	Ghott-Eroman	Man-made structure species	Shajara Fishing Port	Exposed man-made structure
ESI 1B	Al Garaboly	Man-mad structure species	Al Garaboly Fishing Port	Exposed man-made structure
ESI 1C	Sabratah	Rocky cliffs species	Swimming sites	Exposed Rocky cliffs
ESI 2A	Zuwara	Intertidal species and habitats	Swimming sites	Exposed wave cut platform
ESI 2A	Mellitah	Intertidal species and habitats	Swimming sites- Mellitah Port	Exposed wave cut platform
ESI 2A	Sabratah	Intertidal species and habitats	Swimming sites- Fishing sites - Archaeological site of Sabratah- Tuna Factory	Exposed wave cut platform

تم استلام الورقة بتاريخ:6/ 2024/1م وتم نشرها على الموقع بتاريخ:31/ 2024/1م

ESI 2A	Surman	Intertidal species and habitats	Swimming sites	Exposed wave cut platform
ESI 2A	Zawiya	Intertidal species and habitats	Swimming sites	Exposed wave cut platform
ESI 2A	Janzour	Intertidal species and habitats	Swimming sites-Summer resorts	Exposed wave cut platform
ESI 2A	Siahia	Intertidal species and habitats	Swimming sites-Summer resorts	Exposed wave cut platform
ESI 2A	Gargarish	Intertidal species and habitats	Swimming sites	Exposed wave cut platform
ESI 2A	Tajura	Intertidal species and habitats	Navy base-Swimming sites-Fishing sites	Exposed wave cut platform
ESI 2A	Ghott-Eroman	Intertidal species and habitats	Swimming sites-Fishing sites	Exposed wave cut platform
ESI 2A	Al Garaboly	Intertidal species and habitats	Swimming sites	Exposed wave cut platform

3.6 The Oil Risk Map of the Study Area on the Libyan Coast

This study focuses to build the oil spill risk map using an impact assessment of oil slicks on the coastal ecosystem of the Libyan coast. The oil spill risk map demarcates the coastal areas at risk of oil spills and where socio-economic activity may be affected, including coastal habitats and species. The shoreline oil spill risk in the study area is partitioned into three coastal stretches: low, medium and high oil spill risk.

According to the results of the simulation outputs of the oil spill trajectories for 24 scenarios (**Probability**), the high-risk area is concentrated on the eastern coast of Sabratah, Zawiya, Gargarish, Tripoli center, Souq Al Jumaa, and Al Garaboly, while the medium oil risk is spread on the coast in Abu Kamash, Zuwara, and Janzour. The lowest risk segments in the study area are on the coasts of Mellitah, Surman, Al Maya, Siahia, Hai Al Andalus, Tajura, and Ghott-Eroman.

تم استلام الورقة بتاريخ:6/ 1/2024م وتم نشرها على الموقع بتاريخ:31/ 1/2024م

The output of oil spill trajectory mapping on the Libyan coast as presented (**Probability**) is an important tool that helps decision-makers determine the location of spilt oil and quantify it. In addition, a planner can estimate where a hazard from an oil spill may occur and how much time a slick may take to reach the coast. This information allows decision-makers to develop a plan for response options that minimize damage to coastal habitats.

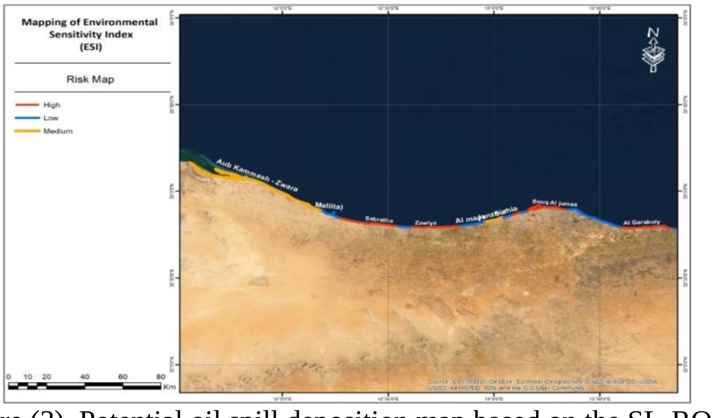

Figure (3). Potential oil spill deposition map based on the SL-ROSS outputs for oil spills on the western Libyan coastline.

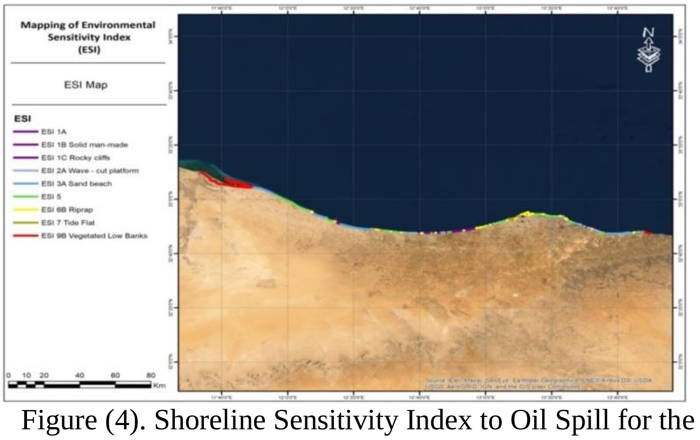

Figure (4). Shoreline Sensitivity Index to Oil Spill for the Whole Study Area.

3.7 Quantitative oil spill riskfor the western Libyan costal

Following the production of the environmental sensitivity and oil risk maps, these were overlapped to compile the final composite

وتم نشرها على الموقع بتاريخ: 31/ 1/2024م تم استلام الورقة بتاريخ: 6/ 1/2024م

map depicting the combination of both to identify the location of high-risk areas, i.e. areas combining the higher probability of being impacted by oil pollution and potential major consequences (IPIECA-OGP,2013; Authority, 2002) calculated using the GIS to extract the level of risk of oil spills in Al-Bouri offshore platform.

$$\text{Risk} = \text{Frequency X Consequences} \qquad (1)$$

Where: Frequency is oil risk map (Fig 3) and Consequences is environmental sensitivity maps (Fig4).

In order to develop guidelines for an oil spill event, assessments for shoreline segments are established according to their sensitivity level and oil spill risk (Azevedo et al., 2017). An analysis of the coastal segments is carried out, covering 16 sections along 365 km of rocky shores and sandy beaches. There are several types of shoreline classes, covering the whole range of the sensitivity index values.The lowest sensitivity shoreline type includes parts of all shoreline sections distributed along the coast (Table.4), and classified as ESI1A, ESI2A, ESI1B, and ESI1C. The medium sensitivity locations correspond to sandy beaches, classified from ESI 3A–ESI 5B, including 15 shoreline sections (Table 3), while the 14 high sensitivity areas, classified from ESI 6B–ESI 7, represent riprap beaches and tidal flats (Table 2). The very high sensitive areas, ESI 9, are located on two shoreline segments, Abu Kamash and Al Garaboly, as shown in Table (1), representing vegetated low banks on the wetland coast.

According to the shoreline oil spill risk maps (Fig3), each segment is classified according to oil spill deposition maps in the oil spill simulation, which is divided into three-level risks: (1) high, (2) medium, and (3) low oil risk.

The results of a cross-tabulation of risk and sensitivity data illustrate that there are two very high-sensitivity shoreline segments located in oil spill risk areas (Table5- Fig5). The high oil risk areas have a length of 3.30 km along the eastern Al Garaboly coast (Fig5), while the length of 65 km is a medium oil risk area on the western Libyan coast at Abu Kamash, which represents a vegetated low bank on the wetland coast. With the absence of low-sensitivity areas in high-oil-risk areas, these very high-sensitivity areas at high and medium risk are clear targets for prioritization in any management plan for oil spills on the coast. The high-sensitivity ESI represents riprap beach and exposed tidal flats categories, covering 23.02 km of the shoreline in the high oil risk area at Sabratah, Zawiya, Gargarish, Tripoli center, Souq Al Jumaa, and Al Garaboly (Table 5), while covering approximately 6 km in the medium oil risk area on the western Libyan coast as Abu Kamash, Zuwara, and Janzour. In addition, the areas with a length of 11.04 km are under low oil spill risk of the high-sensitivity shoreline at Mellitah, Surman, Al Maya, Siahia, Hai Al Andalus, Tajura, and Ghott-Eroman.

Table (5).Shoreline sensitivity classification under coastal oil risk, with the estimated total length of coastline segments.

Oil spill hazard map / Map of sensitivity area	High risk	Medium risk	Low risk	Total (km)
Very high sensitivity	3.30	65	0	68.3
High sensitivity	23.02	5.96	11.04	40.02
Medium sensitivity	49.98	39.19	14.79	103.96
Low sensitivity	69.74	19.1	64.35	153.19
Total (km)	146.04	129.25	90.18	365.47

The study found that the medium-sensitivity areas with medium oil pollution risk are covering on 63.7 km of the western Libyan coast. The rest of the medium-sensitivity shoreline appears in the low oil risk area, covering 14.79 km of the coast.

The geographical areas of the low-sensitivity shoreline are between the west and east coasts of the study area, with a total length of around 153.19 km, which is the largest area of segments, located in oil spill risk areas. However, 69.74 km of the low sensitivity area that falls within the shores is considered at high risk according to the oil spill simulation maps, while 19.1 km of the shoreline is at medium oil spill risk. Moreover, 64.35 km of the low-sensitivity shoreline is under low oil risk as shown in Table (5).

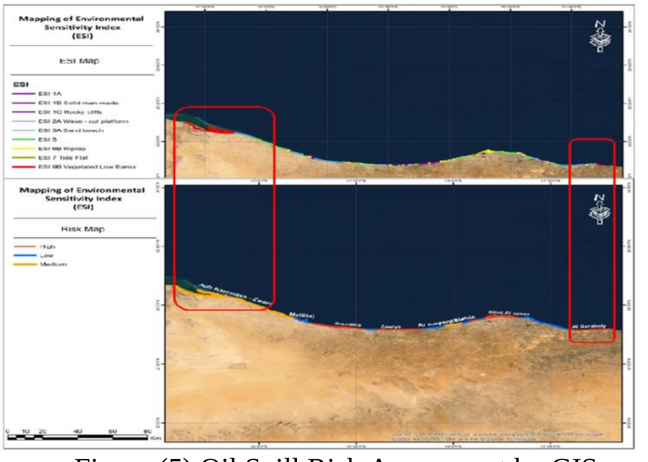

Figure (5).Oil Spill Risk Assessment by GIS

4. Conclusion

An oil spill is one of the main pollutants affecting the marine environments along the Libyan coast.This work has developed environmental sensitivity maps for the purpose of dealing with different coastal sensitivity levels for oil spill events in the area.

The risk assessment of the shoreline segment, which covers 365 km, was based on a shoreline oil risk map from the analysis of the oil spill movement scenario database and the ESI index database. These databases were compiled and stored using the GIS, from which hard copy maps were created at different scales depending on their purpose.

The result of the modeled coastal oil spill shows that the majority of the study area between Abu Kamash and Al Garaboly shoreline faces a high oil spill risk along the western and eastern coast. The findings of the oil risk assessment show thata great length of the shoreline (146.04 km, around 40% of the Libyan coast) in the study area faces a high oil spill risk level while 129.25 km of the shoreline (35% of the Libyan coast) faces a medium oil risk level. In addition, the shoreline of 90.18 km faces a low oil spill risk level, representing 25% of the whole shoreline.

The ESI maps provide a spatial view of coastal resources that could be at risk in the event of an oil spill. Furthermore, ESI maps are used during the planning process to identify sensitive areas prior

تم استلام الورقة بتاريخ:6/ 2024/1م وتم نشرها على الموقع بتاريخ:31/ 2024/1م

to an oil spill event. During a spill, ESI maps help prioritize response efforts in the most sensitive areas and identify the best protection strategies for the particular resources occurring within the spill area

5. Recommendations

- Monitor and improve the emergency response to oil pollution in the marineenvironment, ranging from oil spill accidents to deliberate and daily oil discharges of oilas part of cleaning the tankers or getting rid of ballast water.
- Give the highest priority of response whenever practicable to sensitive habitats and species that are likely to be adversely affected by potential oil spills, such as Farwa Island.
- Expediting and collaborating to produce a national contingency plan by the Libyan authorities, that is representing the Environment General Authority, the National Oil Corporation, and the marine authority.

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