Title	Oil spill assessment and coastal zone management planning for the Misratah coastline, Libya
Author(s)	Maitieg, Abduladim Salem
Publication Date	2017-08-15
Item record	http://hdl.handle.net/10379/7077

Oil spill assessment and coastal zone management planning for the Misratah coastline, Libya

Abduladim Salem Maitieg

Thesis submitted to Ryan Institute, The College of Science. National University of Ireland, Galway

For the degree of Doctor of Philosophy

Supervisor: Prof Mark Johnson

August / 2017

Acknowledgements

First of all, I would like to thank my supervisor, Prof. Mark Johnson, for his encouragement, guidance, patience and constructive comments over the past four years.

This study was possible because of financial support from the Libyan higher education office. I thank the National Oil Corporation and Environmental General Authority in Libya for providing previous technical reports about the coastal and offshore oil and gas industry.

I would like to take this opportunity to thank my GRC committee: Prof. Colin Brown and Dr. Kevin Lynch in the Ryan Institute.

I would also like to thank Dr. Ronán Hennessy in the GIS centre for many useful conversations, which helped me to develop GIS maps in the thesis.

I am sincerely grateful to all the Ryan Institute staff who helped me during my PhD study in the institute, especially Ms. Suzanne Nolan and Dr. Martina Prendergast for their valuable support and constant encouragement.

Finally, and most importantly, I wish to thank my wife for her continued support and inspiration during the last four years in Ireland.

Abstract

Knowledge of the spatial distribution of shoreline sensitivity, coastal resources and habitats vulnerable to an oil spill is crucial for effective coastal zone management. This goal is best achieved if the location of sensitive resources and the potential oil spill deposition areas are identified in advance, allowing protection priorities to be established and clean-up strategies selected to mitigate the environmental consequences of the spill.

The risk of accidental oil spill in Libyan coastal waters might increase in the future, reflecting trends in (a) proposed oil exports from the Libyan coast, (b) increased marine shipping near the Libyan marine area and (c) proposed offshore oil exploration and production in western Libya. Moreover, the national coastal zone management strategy for Libyan coasts has not yet been applied. The poor coastal infrastructure, limited management facilities and the lack of oil spill monitoring and emergency plans, might increase spill impacts on coastal resources and habitats, making oil spills more complicated and increasing removal time. Therefore, a new regional oil spill management plan is developed for this thesis.

A number of steps are required to build the scientific basis for the management of oil spills. Resources need to be identified and mapped, and those at most risk need identifying. The thesis builds a case study by identifying and mapping information on coastal resources, with an emphasis on coastal oil spill risk along the shoreline of the Misratah region. Three components were developed and integrated into evaluations of coastal risk from oil spills: (1) identification of biological, economic and cultural resources and their potential sensitivities to oil spills, (2) application of the Environmental Sensitivity Index (ESI) approach, and (3) oil spill simulation modelling. The outcome is the first reliable, high-resolution coastal zone strategy for the area, which can serve as a tool for shore-based management.

The audit of cultural and natural resources identified areas of considerable wildlife value (for migratory birds and sea turtles), alongside sites of historic importance and local industry (fishing, saltpans). Particular features of the Libyan coast include wells on the shore close to the sea, and beaches protected by offshore reefs that may break the surface. The Environmental Sensitivity Index (ESI) methodology was used to summarise potential vulnerability of sections of the coast on the basis of coastline morphology. Eleven shoreline classes were described in the study region, with vegetated low bank shores, ESI 9, as the most sensitive, and the exposed rocky shores and exposed man-made structures (ESI 1 and ESI 1 A) the least sensitive.

To quantify potential oil spill pathways, the GIS-based simulation GNOME (General NOAA Operational Modeling Environment) was used in simulations of summer and winter seasonal conditions. This process identified coastal areas at higher risk of receiving spilt oil and the likely behaviour of oil slicks on the sea surface in the different seasons.

The integrated oil risk assessment methodology applied in the thesis produced 43 ESI maps, covering 248 km of the Misratah coast. The shoreline areas most sensitive to oil spills are on the Eastern coast of the region. These are shores of ecological importance as coastal wetlands, turtle nesting areas and habitats for migratory birds. The risk of spilt oil reaching these high-sensitivity areas is relatively low, due to prevailing winds and currents. Approximately half of the 128 km of very high sensitivity shore was at medium risk of spills. This 128 km can be a priority for management measures, along with 12 km of high and medium sensitivity shores at high risk of oil. The majority of the shoreline faces a medium oil spill risk, especially along the North coast where potential oil spill resources are located.

Overall, the thesis provides new information on both the littoral of Misratah and sources of oil, including identifying sensitive areas at most risk of pollution. This information can form the basis of coastal management for the region and communication with stakeholders. A fuller picture of the impacts of oil spilt in the region needs better monitoring infrastructure and consideration of links to the ecosystem services provided by fishing, tourism and salt production.

List of acronyms

ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
RC	Remote Sensing
NOAA	National Oceanic and Atmospheric Administration
ICZM	Integrated Coastal Zone Management
CZM	Coastal Zone Management
ESI	Environmental Sensitivity Index
NEST	National Environmental Study Team
SPDC	Shell Petroleum Development Company
EGA	Environmental General Authority
NOC	National Oil Corporation
GNOME	General NOAA Operational Modelling Environment
GOODS	GNOME Online Oceanographic Data Server
DTM	Digital Terrain Model (also as DEM = Elevation model)
UN	United Nation
IUCN	International Union for Conservation of Nature
NCOM	Navy Coastal Ocean Model
FAO	Food and Agriculture Organization of the United Nations
MSP	Marine Spatial Planning
CYCOFOS	Cyprus Coastal Ocean Forecasting and Observing System
USGS	United States Geological Survey
EMODnet	European Marine Observation and Data Network
COGOW	Climatology of Global Ocean Winds
OPEC	Organization of the Petroleum Exporting Countries
REMPEC	Regional Marine Pollution Emergency Response Centre

List of acronyms

NCB	National Contingency Plan
UNEP	United Nations Environment Programme
PMTP	Protection of the Marine Turtle Program
CMSP	Coastal and Marine Spatial Planning

Table of contents

List of Figures

List of tables

Chapter 1: General introduction and background

1.1 General introduction

The Libyan coastal and marine area is at a high risk of oil pollution from global oil tanker routes and the routes connecting Libyan oil exporting ports with the Western basin of the Mediterranean Sea (Environmental General Authority, 2004). Frequent oil spills are carried through sewage pipes from urban areas, factories and harbours. The lack of reliable historical records for oil spills, along with weak monitoring and minimal responses to spills, increase the threat and impact of oil pollution on coastal habitats and species. Coastal and marine environments contain many sensitive species, habitats and resources that can be affected by oil. Thus, protection of the coastal area from oil spills is a high priority for Libya. In order to fight contamination from coastal and marine oil spill successfully, Libya must have an effective oil spill response strategy.

Definition of the features of coastal areas is important for oil spill management because vulnerability to oil contamination varies between shore types. The shoreline topography is a fundamental feature, central to understanding coastal dynamics and also playing important roles in both physical and biodiversity related classifications (Boak and Turner, 2005). Topography is linked to the persistence of oil on a shoreline. Integrating such information on shoreline sensitivity and natural clean-up capacity is central to the management of coastal resources and emergency plans (Yanez-Arancibia et al., 2004). A useful tool for this integration is to classify shores by an environmental sensitivity index (ESI, NOAA 2002). Emergency plans can reflect decision makers' judgements, which in turn affect the governance and management of the coastal environment during an oil spill.

Given the perceived need for Libyan oil spill response strategies, this thesis aims to develop a coastal oil spill management plan for the Misratah coast. A central task for this goal is to build a geodatabase of coastal and marine information (Pincinato et al., 2009). Wind directions and speeds, currents, bathymetry and coastal topography all influence where oil spill is deposited in the coastal zone. Therefore, oceanographic and climatological data can be used to interpret oil slick movement (Alves et al., 2014) and potential locations for oil deposits on shoreline areas (Santos and Andrade, 2009).

The Libyan coastline is not well described in the existing literature. This chapter will describe the underlying physical setting and the oil industry in the region. The conclusion of the chapter outlines the research approach and chapter structure for the thesis. Although the coastal and marine commission in the Libyan Environmental General Authority (EGA) has been working since 1990s to reduce environmental pressures and improve strategies to protect the coast, oil spills and coastal development are continuing issues. Addressing these issues is made harder by the absence of an integrated coastal zone management plan. Furthermore, efforts to sustainably manage the coast are hampered by a lack of accurate data, a problem facing many southern Mediterranean countries (Daffonchio et al., 2013). Until now, no study has focused on evaluating Libyan coastal resources for coastal zone management. This study develops the tools and knowledge for a discussion of coastline risk from oil spills.

The thesis is mostly concerned with Misratah - also spelt Misrata or Misrutah - a city and a district in North-western Libya, 200 km to the East of Tripoli, with a shoreline of 248 km (out of a total of 1770 km for Libya). The area lies between 32°33'37" and 32°23'48"N, 15°22'58" and 14°36'47"E. The study area (Figure 1A-B) has a population of 400,000 people (Bureau of Statistic and Census Libya, 2016) and includes a large port and a range of wetland habitats used as nesting areas for sea turtles (UNEP, 2010) and feeding places for migrant birds (Etayeb et al., 2007). The coast also hosts several anthropogenic activities, including fishing and tourism. The coast has two distinct shore types: the North and the East coast (Figure 1D). The Northern coast is quite straight with narrow cliffs covering approximately 50 km, and different types of shoreline, such as rocky beaches, boulder shores and sandy patches between coastal headlands (Aniba, 2007). Most human activities take place on the North coast, e.g. fishing, tourism, industry, ports, oil platforms, oil storages and coastal development. Therefore, most of the local oil spills are located on the North coast. The Eastern shore is a low-lying area, mainly composed of wetland coasts. Socio-economic activities are limited to the salt industry and two seasonal fishing harbours.

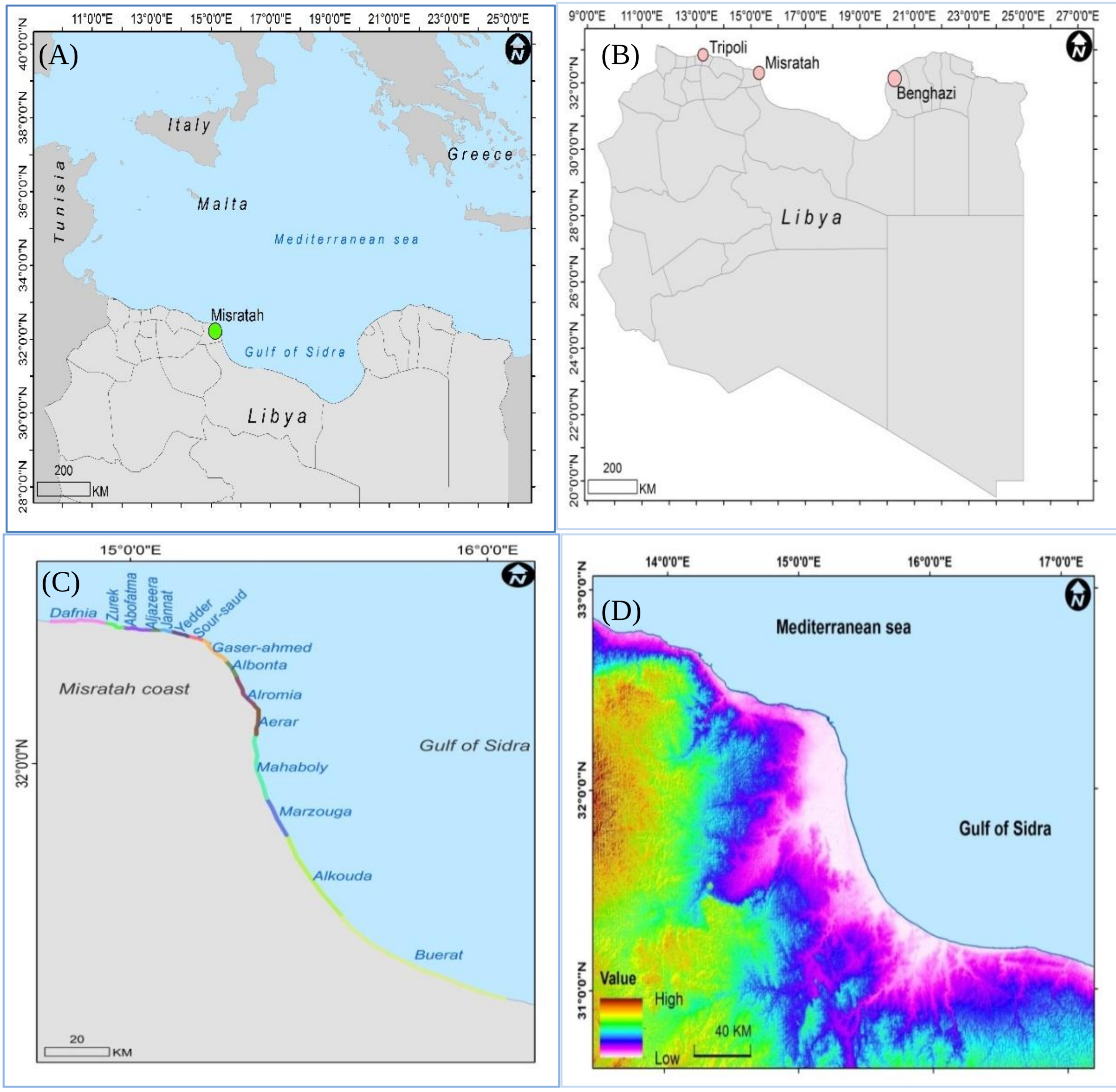


Figure 1 The study area located within the map (A) is the central Mediterranean Sea. The coastline is potentially impacted by spills occurring at any point of the loading and shipping of oil between the Libyan oil export ports and southern Europe. In the map (B) the location of the study area on the Libyan coast with other major cities is indicated. (C) Local shoreline names. (D) Onshore elevation map (DEM) for Misratah (USGS, 2014). White indicates levels between -5 and 5m. The breadth of the white colour on the eastern coast indicates an extensive low-lying coastal strip. Rapid transitions through purple to blue indicate cliffs transitioning between 4 to 40 m in elevation, particularly evident on the northern coast.

1.2 The Mediterranean Sea

The Mediterranean is a semi-closed basin described by Rodríguez-Rodríguez et al. (2016) as one of the most highly valued marine environments in the world (MEDPAN, 2013., UNEP-Map(Rac/Spa) 2010) and containing many distinct coastal and marine ecosystems (Katsanevakis et al., 2014). For example, the Libyan coast was recorded as one of the most important nesting areas for loggerhead turtles (*Caretta caretta*) and resting places for migratory birds. The Libyan marine area (Figure 2) is bordered by Egypt, Greece, Italy, Malta and Tunisia (UNEP/MAP, 2012) and extends between 30° 15' 50" N' and 35° 13' 30.7"N and 11° 31' 33.9" E and 26° 12' 26"E. Libyan coastline forms part of the southern boundary of the central Mediterranean Sea basin, covering 1,770 km. The coast is important for tourism, industry and fishing. Libya has a population approaching 6.202 million, concentrated along the coast (Bureau of Statistics and Census Libya, 2016).

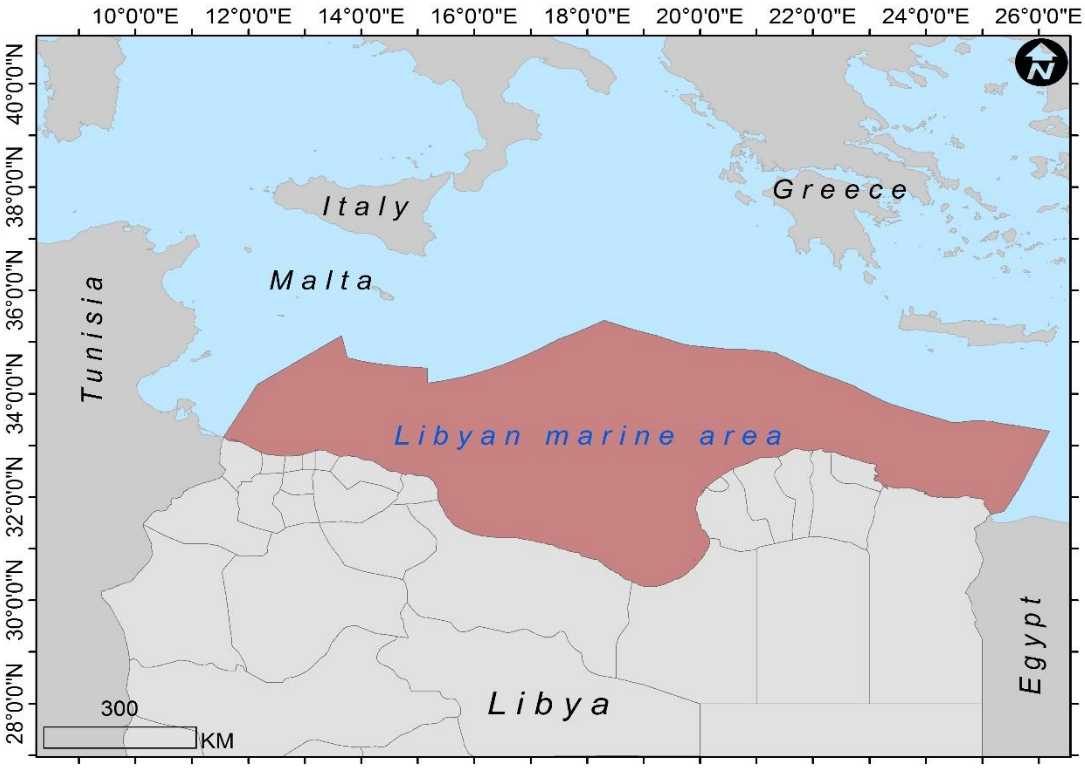


Figure 2 Libyan maritime boundaries (Marine Regions, 2017)

1.2.1 Bathymetry and sea depth

The purpose of discussing regional bathymetry is because variations in depth and subsurface topography interact with ocean current circulation (LLP, 2010; Alves et al., 2014). Such interactions can block or steer seawater flows and further modify local current directions and speed, hence influencing oil spill routes (Alves et al., 2015). For example, bathymetric data used by Alves (2015) in an oil spill prediction model influenced oil spill trajectory offshore of Crete in the Eastern Mediterranean. Similarly, Dalyander (2014) used high-resolution bathymetric imagery to assess the mobility and redistribution patterns of sand and oil agglomerations in the surf zone of the Gulf of Mexico (Dalyander et al., 2014). These studies show that bathymetric, meteorological and oceanographic conditions are the main factors controlling the trajectory of oil slicks on the sea surface (Alves et al., 2015).

The Misratah marine area consists of contrasting seabed elevations between the northern and the eastern coast (Figure 3A). The seafloor on the north coast has various bathymetric features, including steep gradients with irregular depths. On average the coastal water is deeper in the North compared to the Eastern coast. The sea depth contour map (Figure 3B) shows the depth lines running parallel and near to the shoreline with a maximum depth of 15 m at the Dafnia and Zurek shores, with a gradual decrease in depth towards the eastern coast. The eastern water depths near the shore are as shallow as 1 m (Table 1 Appendix 5). The seabed of the Gulf of Sidra slopes gently with a smooth relief.

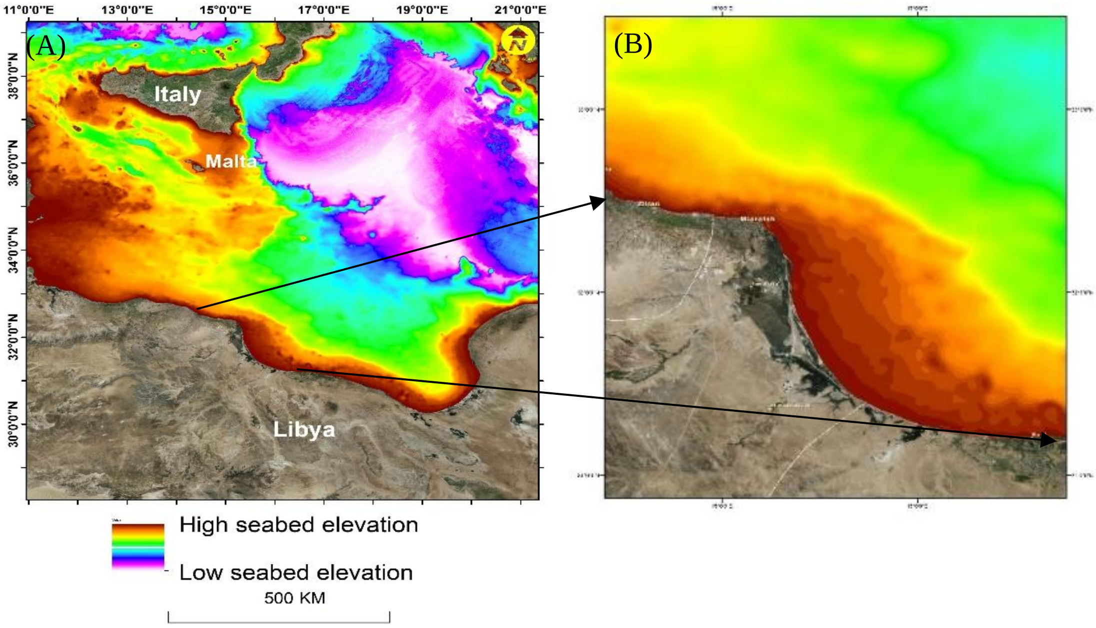


Figure 3 (A) Bathymetric maps for the central Mediterranean (B) Bathometric level of Misratah coast, data derived from (EMODnet, 2015). Of note is the steeper profile of the north-facing coastline, compared to the broad shallow Gulf of Sidra in the east.

1.2.2 Coastal shape and topography

The potential impact of an oil spill on reaching the shore depends on wave exposure, shoreline slope and the physical make-up of the shore (Oliveira et al., 2013). Studying shoreline structure is therefore necessary to understand coastal risk level and the management and vulnerability of coastal areas to oil spill. In Misratah, there are several coastal environments, including rocky/sandy beaches and coastal marshes. Eleven examples of shoreline types were found (Figure 4). Each shoreline type can be classed into a specific environmental sensitivity to oil (Chapter 3).

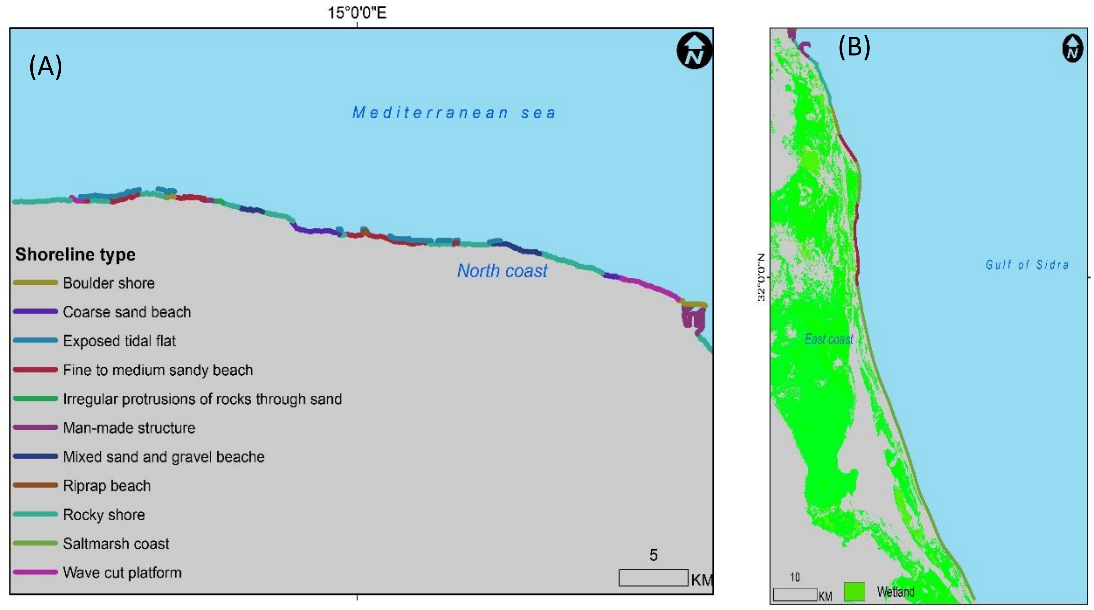


Figure 4 Main coastal types on the northern (A) and eastern coast (B) of Misratah. The topography of the study areas vary between the north and east facing coasts. Sandy beaches, narrow rocky shores, headlands and manmade structures define the north coast, whereas the eastern shoreline is mainly composed of beaches backed by seasonal wetlands and saltmarsh.

The Northern shore from Dafnia to Gaser-ahmed is characterized by high vertical cliffs with narrow sandy and rocky shores and patches of gravel beaches. The shoreline is mainly composed of rocky shores and sandy patches between small headlands, where the coastal banks are very close to the shoreline (Industrial Research Centre, 1975). The eastern coast from Gaser-ahmed to Buerat is within the bay of Sidra (characterized as semi closed sea) and is relatively flat to gently sloping. In the Gaser-ahmed region, the coast is described as having a wider shoreline than the North coast embayed by saltmarsh with small backshore dunes.

A feature of the rocky areas is the presence of rocky reefs offshore, which can rise as steep walls above the water surface in summer season on the North coast. This feature is spread throughout the nearshore area where the rocky and sandy shores extended (Figure 5B). The wall-like structures can be considered as a second mechanism influencing oil slick movement to the shoreline area (Oyedepo, 2011). The coastal reefs generally have environmental and economic values (Figure 5B, C): by protecting shore areas used as harbours from high wave. In addition, the rocky reef is a feeding and resting area for local and migratory seabirds (Figure 5D).

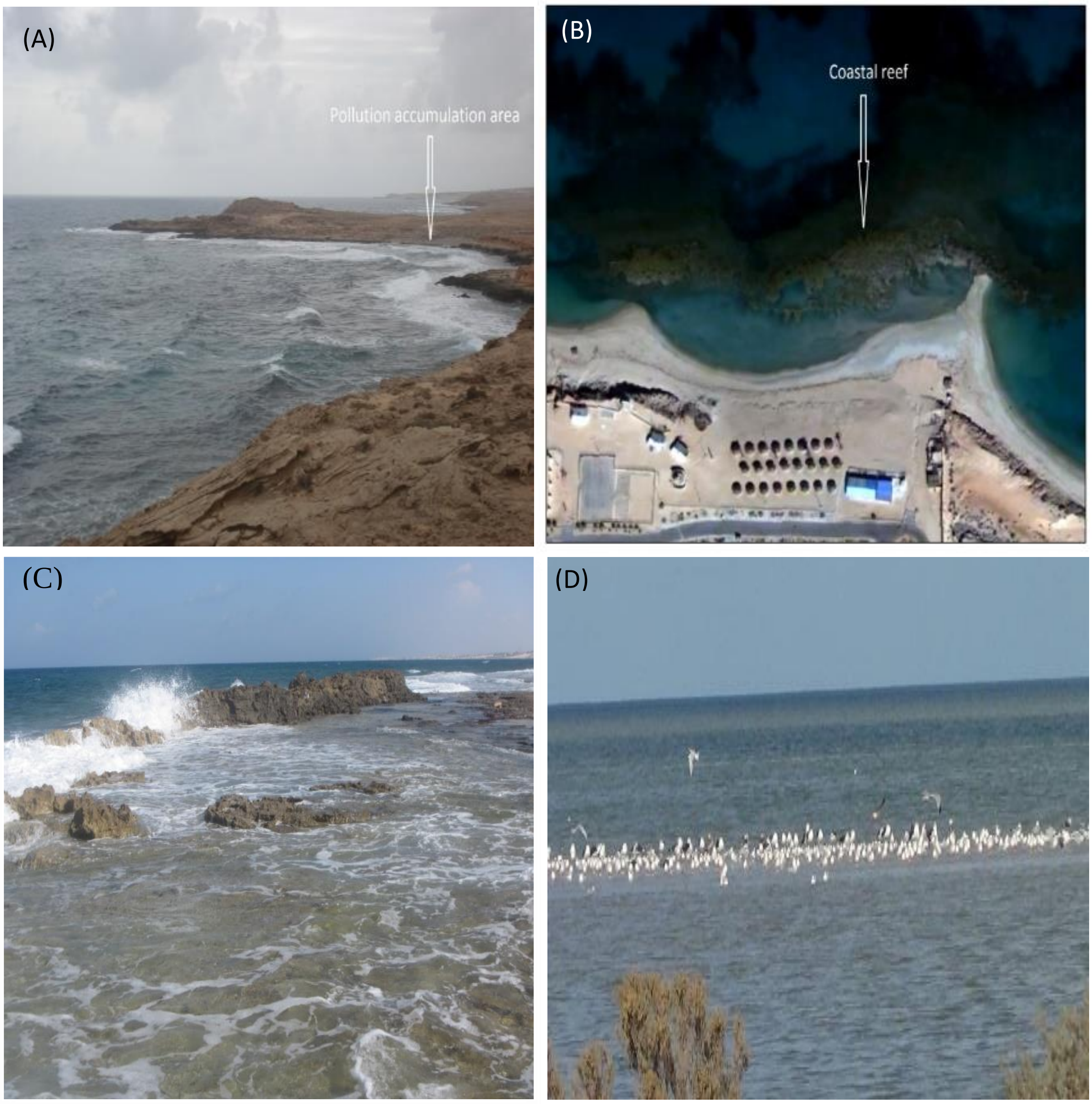


Figure 5 Physical shoreline features that contribute to the sensitivity of coastlines to oil spills. (A) shows headlands on the north coast of Misratah, (B) present rocky reef at foreshore area, (C) exhibits reef with vertical protrusions at foreshore, and (D) submerged rocky reef used as habitats for local and migratory birds.

1.2.3 Wave, currents and winds and energy

1.2.3.1 Wave

Wave energy generated by winds blowing over the sea surface depends on (1) wind speed and frequency and (2) the amount of open sea water (fetch) over which the wind blows (Badejo et al., 2003). The Libyan marine environment is characterized by marked short-term fluctuations in wave energy and height, reflecting a complex pattern of northern and eastern winds, with dry winds mostly originating from the south to south-west. The northern coast can be characterized as open sea with high wave energy, compared with the low wave energy of the eastern coast (National Centre for Meteorology, 2017).

The most prevalent directions of waves during winter are from the north and northeast, towards the south and southwest, with wave heights of 3 to 5 m (Figure 6). In the dry season, waves often originate from the north over the Mediterranean basin and arrive at the Libyan coast with an average height of 0.5-1 m. Because wave energy can move slicks on the sea surface toward the coast, and plays a significant role on tar ball distribution on coastal areas (Nemirovskaya, 2011;Warnock et al., 2015), oceanographic data are required to develop a management plan for coastal oil spill (Abascal et al., 2010). Understanding wave energy is necessary for developing environmental sensitivity index values and coastal classifications (Harvey et al., 1999). For example, large waves can be reflected from some shores, keeping oil offshore.

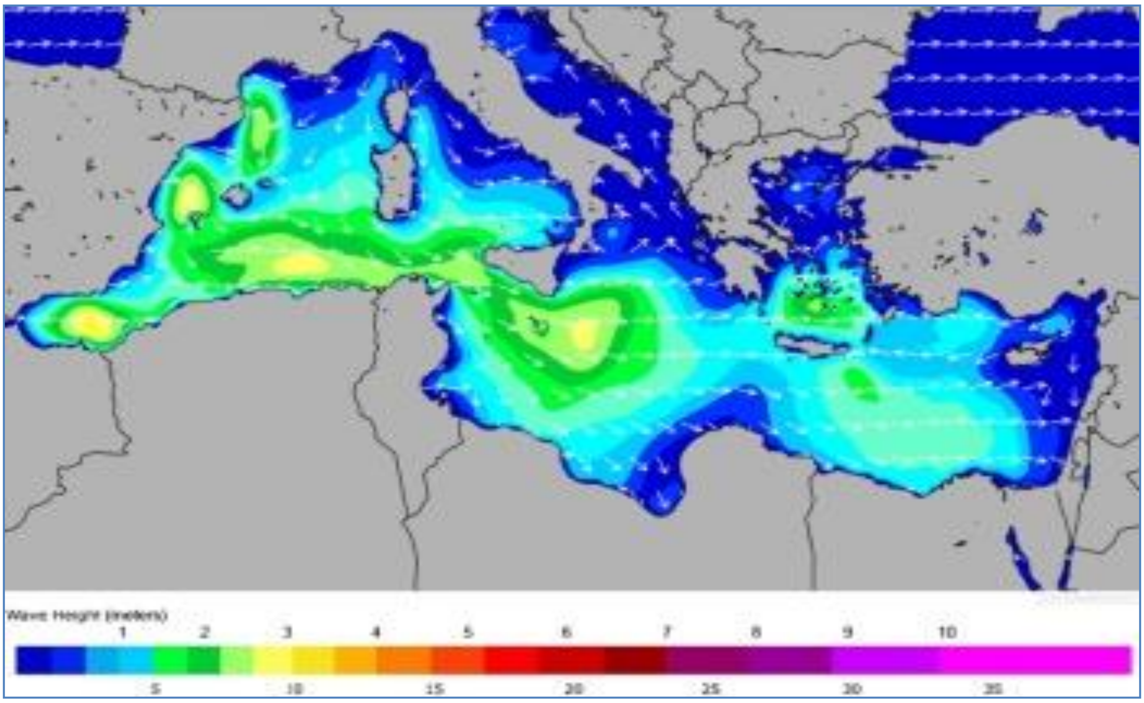


Figure 6 Significant wave heights and directions along the Mediterranean Sea.The colour bar shows the level of the wave high. (CYCOFOS, 2017).

1.2.3.2 Currents

Mediterranean currents are generally on smaller scales and with less intensity than those of the open ocean (Menna and Poulain, 2009). The Libyan marine basin contains a major feature in the Gulf of Sidra (Figure 7A), which plays a significant role in controlling the current and eddy circulation in the Libyan marine area (El-Geziry, 2010). Two types of current dominate the regional circulation. Water of Atlantic origin, supplied through the Straits of Gibraltar, flows eastward flow along the Libyan and Tunisian slopes and continues in a cyclonic circuit to Egypt (Figure 7B) (El-Geziry and Bryden, 2010). However, in the summer season, a current flows in the channel between Sicily and Tunisia toward to the Libyan marine basin in two branches (Figure 7C, D). One branch flows parallel with the Misratah coast to the Gulf of Sidra, the other forms eddies over the Libyan sea. The local flow during summer season (Figure 7D) creates eddies between Malta and the western Libyan coast near Misratah, oriented toward the Gulf of Sidra.

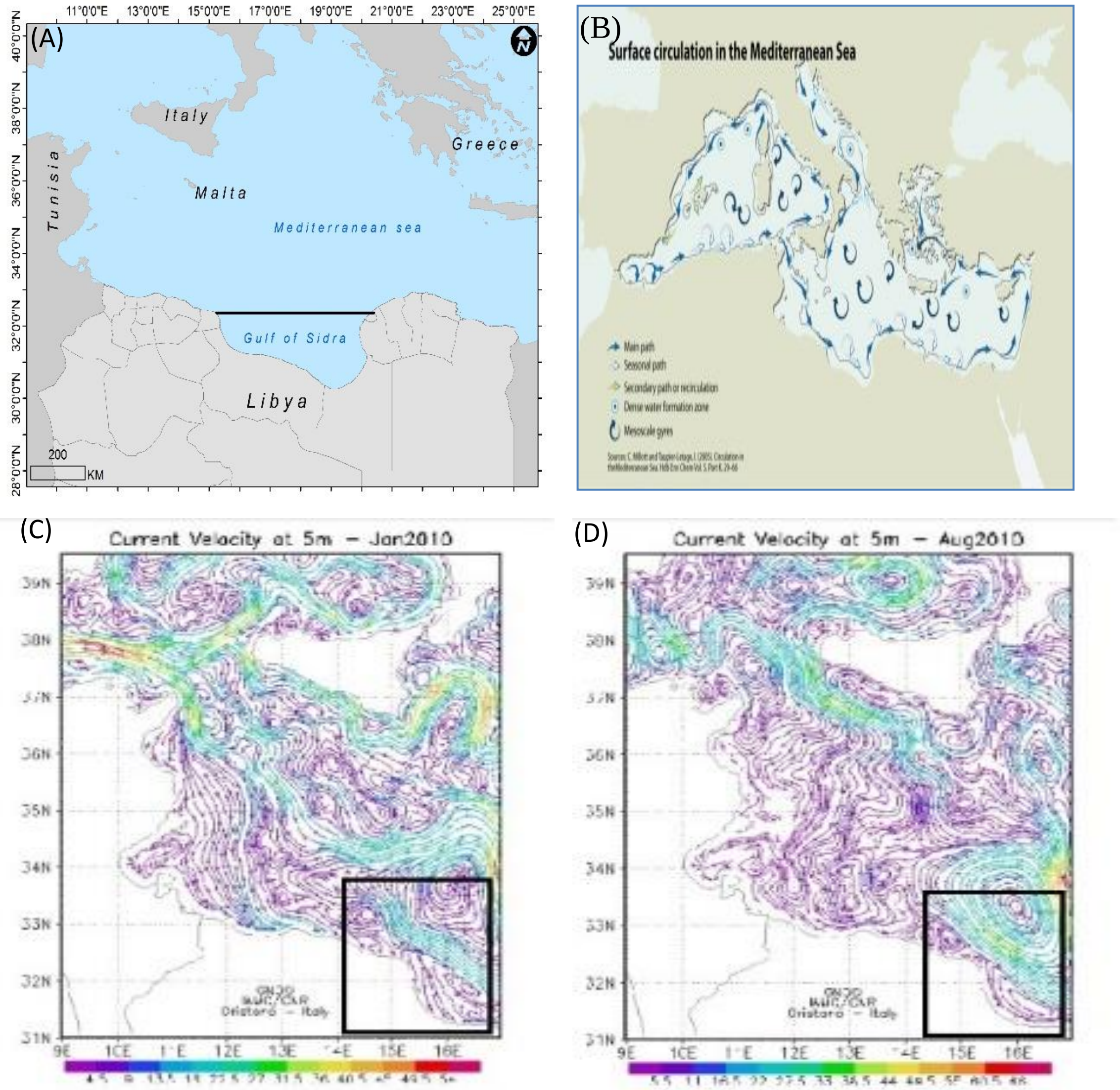


Figure 7(A) Gulf of Sidra location at Libyan coast, map (B) shows the main path of surface circulation in the Mediterranean, The predicted currents are very small. The maximum annual predicted depth-averaged current speed is only 0.01 m/s. (Global ocean current models, 2015), maps (C) and (D) gives an idea about the path of seasonal current surface in July and January 2015, (Poulain et al., 2012). The Mediterranean current in winter season start off to the Southwest of Malta, from the North to the South of the Gulf of Sidra and flow generally in a westerly direction. In the summer season, however, the current direction continues in a generally northwesterly direction toward the Gulf of Sidra with a small current circulation reaching the Libyan coast. (The Operational Oceanography group-IAMC- 2015).

1.2.3.3 Winds

Winds are key drivers of oil movement on the sea surface and tar ball deposition (Warnock et al., 2015). Understanding the trajectory followed by spilt oil is important for improving coastal oil spill emergency plans (Pashna et al., 2014). The general wind rose of Misratah (Figure 8) is taken from the Climatology of Global Ocean Winds (COGOW), based on ten years (January 1999 – December 2000) of QuikSCAT observations (COGOW, 2016; Risien and Chelton, 2008). Winds originate mostly from the west and northwest in the winter, while north and northeast winds occur in the summer. From April to the end of summer, the Libyan coast is under the influence of Ghibli winds, which are dry and hot (Mohammed and Milad, 2010).

The prevailing wind speed in the winter is between 9 and 16 knots. In the summer, the average wind speeds are lower, between 6 and 7 knots.

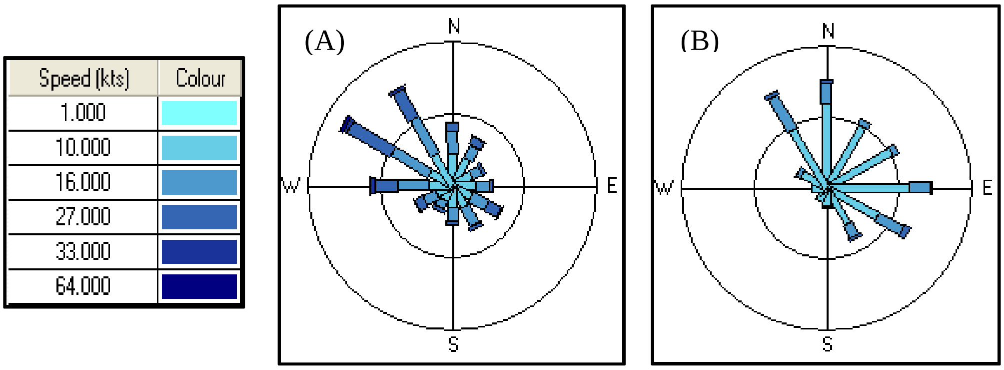


Figure 8 Wind roses of Misratah coast showing wind speed and direction in the winter (A) and the summer season (B). During the winter, winds are stronger, dominated by mean daily speeds of 16 knots or more between south-south-west and north. Summer directional wind distribution within the area of interest shows the majority of wind from the north, northwest and east.

1.3 Key concepts

1.3.1 Libyan oil industry

The oil industry provides an important foundation for the economy and development in Libya, with increasing offshore and onshore oil exploration after 2005. Libya has the largest amount of proven crude oil reserves in Africa (National Oil Corporation of Libya, 2016). The area has become one of the most important oil producing regions in the Mediterranean region; Libya became an oil exporting state in 1961 when it joined the Organization of the Petroleum Exporting Countries (OPEC).

Although the average of oil production before 2011 was over 1.65 million b/d, Libya's oil and gas production and exports have been substantially affected by civil unrest over the past few years (GeoExpro, 2016). Libyan crude oil production has decreased to 350 thousand b/d in 2016 due to the unstable political situation. Typically, 84% of the Libyan crude oil is exported through the Mediterranean basin to the North Mediterranean countries (Espon, 2013; UNEP, 2008) via pipelines and oil tankers to European countries such as Italy (28%), Greece (5%), Spain (10%), France (15%) and Germany (10%).

The major oil and gas producing areas and sites of oil terminals are distributed within three sections of the Libyan coast; (1) on the Western coast near Tripoli 250 km West of Misratah, (2) on the coast of the Gulf of Sidra, (3) on the Eastern part of the Libyan coast close to Tobruk city in the Cyrenaica region (Figure 9A). According to the Braga oil company database, the company holds oil stores near to Misratah coast and an oil platform situated in the Gaser-ahmed marine area. The Misratah oil stores received approximately 1,391,964 tons of heavy oil and gasoline per year via oil tanker, which comes from different refineries in the Mediterranean countries (Brega Petroleum Marketing Company, 2015). Figure 9B illustrates the oil tanker network between the Misratah ports and oil refineries in the Mediterranean countries, and between the Libyan oil exporting ports and the oil stores complex as well. These oil tanker routes in the Misratah marine area are possible oil release sources related to oil transportation operations, such as oil loading/ uploading.

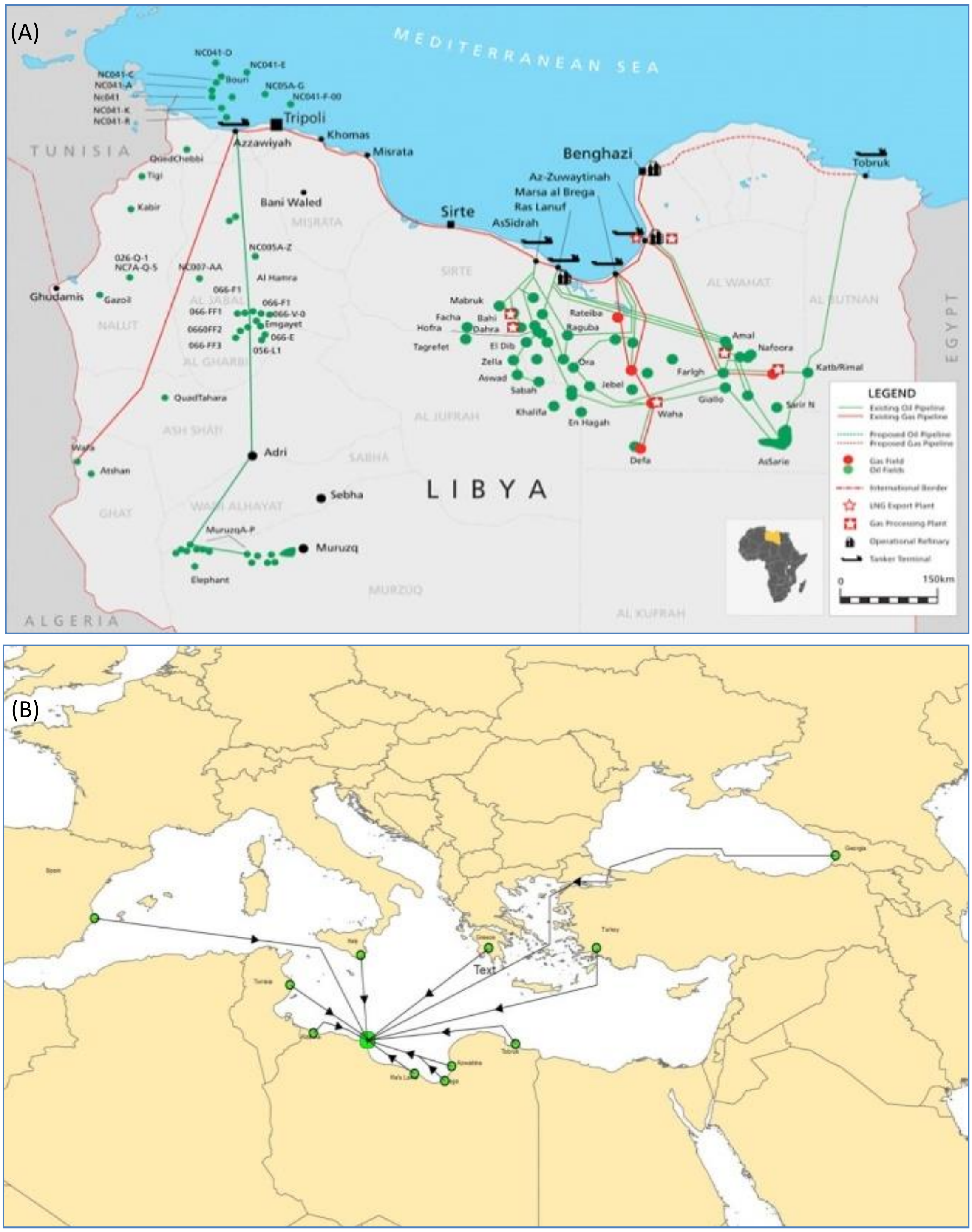


Figure 9 Map (A) discloses oil and gas production sites which are located by the side of Libyan coast (National Oil Corporation of Libya, 2016), (B) unveils oil tanker roads between Misratah port and refineries in the Mediterranean countries. The map B which is created in ArcGIS was adopted from annual reports of the Misratah port in 2014.

1.3.2 Oil pollution sources

The effects of oil pollution on coastal environments can lead to negative environmental impacts on habitats, species and coastal resources in the short and long term (Brenner, 2015) that depend on the amounts of the type of oil spill and the vulnerability of the affected coastal resource (Samaras et al., 2014).

The Mediterranean coastal ecosystem has been considered highly sensitive to oil spill (Daffonchio et al., 2013). The central Mediterranean Sea is recognized as the second-most spill-affected area in the region between 2000 and 2009. The United Nations Environment Programme reports state that approximately 55,000 m tonnes of crude oil were spilled through the area near Malta, Tunisia, Italy and Libya (Figure 10) (UNEP/MAP, 2012). The Libyan coastal area is at a high risk of oil contamination from the tanker routes connecting the Southern and Northern basins of the Mediterranean Sea. The number of ships and oil tankers landing in the Libyan ports was between 3,500 and 4,000 /year (Libya Shipping Agency, 2016). Furthermore, frequent oil spills and the absence of Libyan oil pollution control efforts are associated with long-term consequences, including harming the coastal species and habitats, as well as socio-economic activities.

The largest oil spills in the study area have recently been associated with oil loading accidents on the platforms. For instance in 2014, approximately 500 m^3 were spread onto the sea surface during oil loading operations. In addition, the deteriorating condition of the pipeline that links oil platforms on the coast to storage inland also increases the risk of oil pollution. In 2013, around 100 m^3 of heavy oil was spilt from an oil pipeline in the Misratah port. In 2006, approximately 206 m^3 of heavy oil was spilled in the Misratah port when an oil tanker collided with the landing stage.

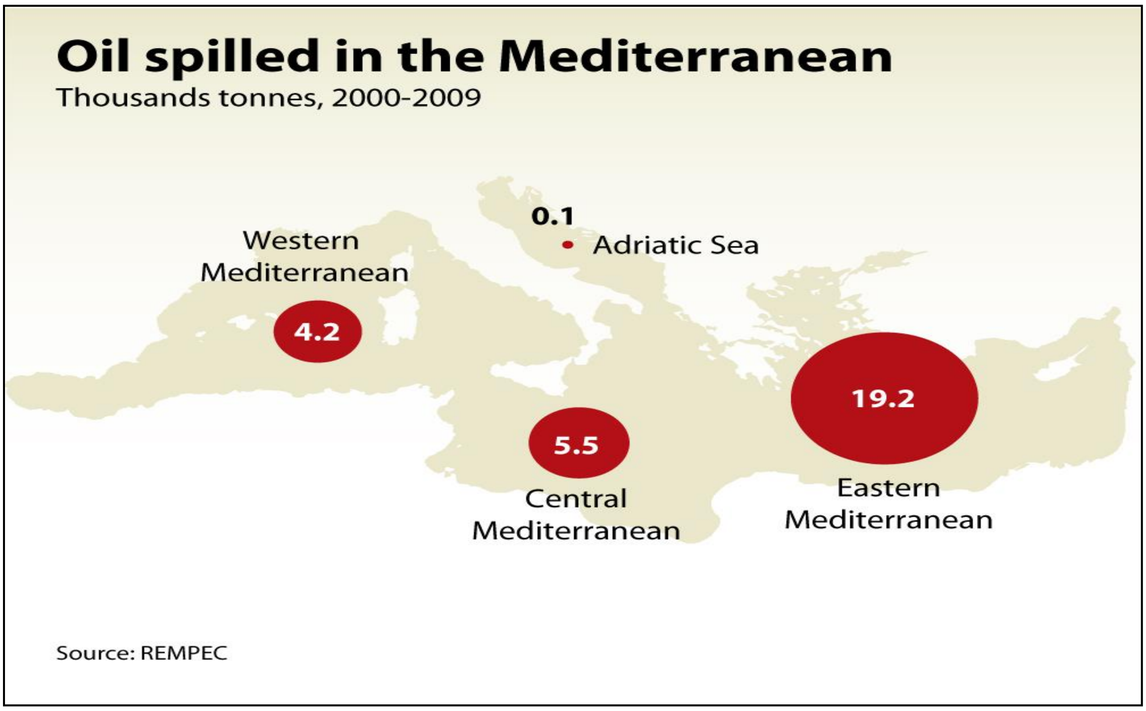


Figure 9 Oil spill in the Mediterranean for the period 2000-2009(REMPEC, 2017).

1.3.3 Oil spill impacts and pathways

Crude oil and oil products contain a wide range of compounds that can affect coastal habitats and species (Grant and Briggs, 2002). In the case of slicks reaching a shore, the immediate impacts can be from smothering, preventing access to oxygen for benthic organisms or compromising feathers and fur in vertebrates. Toxic effects can occur in the short or long term from internal exposure to oil through ingestion or inhalation and through external exposure with absorption through the skin.

The toxic effects of oil on marine organisms are influenced by the concentrations of low molecular weight aromatic components and the period of exposure to these components (Clark, 2001). The low molecular weights make these compounds volatile and they typically evaporate from spilled oil. Up to 40% of the Amoco Cadiz spill (240,000 tonnes) may have been lost this way (Kingston 2002). Other relatively toxic small molecules are soluble in seawater (typically less than 1% of crude oil; Kingston 2002). The remaining oil can become dispersed as small droplets, with some sinking of heavier fractions (particularly if adsorbed to sediment particles). A small amount of oil is oxidized by sunlight into related compounds. Under some rougher sea conditions, the oil droplets can be held in a viscous emulsion or mousse. Mousse formation can extend the life of a slick, and the potential smothering effects if the oil emulsion reaches the coast. The fate of oil spilled at sea is therefore a process that starts with spreading and evaporation of volatile components, followed by losses to weathering: including dissolution, emulsification, and sedimentation; all processes affected by the type of oil and factors such as wave, current and wind energy (Shelton et al, 2002). The direct toxic effects of crude oil in the open sea have generally been thought to be minimal, reflecting the degree of dilution and the loss of toxic components during weathering on the sea surface (Shelton, 1971, Kingston 2002). Oil spills can impact the subtidal benthos if sufficient material sinks.

The dispersal and weathering of oil spills at sea contrasts with different persistence and transformation profiles of spilt oil close to the shoreline (Yoshioka and Madelyn, 2002). Less dilution occurs in shallow waters, the benthos may be more strongly impacted and wave-induced break-up of spills may be reduced. Spills reaching the shore immediately after discharge have a more toxic profile as volatile toxic substances such as aromatic components may not have been lost to evaporation (Owens, 2002). An example of an impact in waters of 17 m depth in the Bay of Morlaix (France) is given by Dauvin (1998). Subtidal benthic communities took over 10 years to recover following contamination associated with the 1978 *Amoco Cadiz* oil spill. In contrast, morphological and cell damage to herring larvae (adults spawn eggs onto submerged algae and seagrasses) was detected for one year only following the Exxon Valdez oil spill (Hose et al., 1996).

1.3.4 Coastal management and the shoreline sensitivity index

Although the details of the approach may vary, most Mediterranean countries have protected coastal areas and have determined vulnerable coastal resources. In contrast, there has not been a national assessment of coastal sensitivity to oil spills in Libya (National Oil Corporation of Libya, 2016). Libya has an obligation, as a one of the signatories to the United Nations Convention on the Law of the Sea (appendix 6), to protect its marine environment (United Nations Convention on the Law of the Sea, 2017). In addition, Libya is signatory to the Mediterranean countries convention on oil spill preparedness, response and co-operation convention (The Regional Marine

Pollution Emergency Response Centre for the Mediterranean Sea, REMPEC, 2017). One of the requirements for REMPEC is to have a National Contingency Plan. As one of the measures that should be taken to meet the obligations of these conventions, the national plan should cover all coastal oil pollution, whether it is from ships, ports and harbours, offshore operation, urban or oil handling platforms.

One of the early steps in forming a regional plan for coastal oil pollution is to make an inventory of the types of coastline present. This goal can be achieved by categorizing shores using the Environmental Sensitivity Index (ESI). An ESI map is primarily used for coastal oil spill management (Gugliermetti et al., 2007). Coastal sensitivity index maps are one of the most widespread tools for summarizing vulnerability to accidental oil spills. The National Oceanic and Atmospheric Administration (NOAA) provides ESI maps for coastal oil spill management, which is applied on the coastal regions in the United States (NOAA-ESI map, 2016). The resulting US coastal sensitivity atlas was used to identify environmental and morphological coastline priorities and provide decision-makers with an overview with which to plan preventive action and emergency responses in an oil spill event (Walther, 2014). A full ESI mapping describes shoreline type and biological and human-use resources, allowing shoreline habitats to be ranked according to the biological value and the shoreline's ability to clean up naturally. Biological resources include oil-sensitive animals and non-shoreline habitats (Scott et al., 2013). Specific areas that incorporate added sensitivity and value to humans such as tourist beaches and coastal aquifers are categorized as human-use resources (Gundlach and Hayes 1978; Michel et al., 1978).

An ESI mapping can be integrated in a coastal zone management (CZM) approach. This involves the management of sensitive areas and an oil spill contingency plan, providing an effective process for decision makers to develop and protect coastal areas and resources in cooperation with local communities and authorities (Knecht and Archer, 1993). Oil spill assessment and management systems were originally proposed to support planning and emergencies (Frazão Santos et al., 2013) but have been successfully applied to several additional contexts, such as flood risk (Singkran and Kandasamy, 2016), sea level rise (Addo, 2014) and climate change (Krishnamurthy et al., 2014). In the context of the related management process of marine spatial planning

(MSP), an ESI mapping can inform the zoning and planning of activities that form a plan.

1.4 Overview of the research process

The originality of the work stems from the application of the Environmental Sensitivity Index in an understudied region. Human factors such as the oil industry, oil tanker transportation and urban sources of oil are considered. A combination of methods (coastal and marine spatial planning, environmental sensitivity index and oil spill simulation) and techniques (ArcGIS and GNOME software) are used to develop coastal zone management for the Misratah coast.

This thesis has an overall methodology that structures the assessment of shoreline sensitivity: integrating physical parameters, socio-economic activity and coastal biological value characteristics to provide specific information for developing a coastal zone mapping strategies for oil spill response (Figure 11). Alongside the sensitivity assessments, which evaluate the status of different sections of shore, a hypothetical classification can be made: one which integrates potential sources and transport routes to evaluate the chance of oil reaching particular shores. This classification can be made using modelling approaches, specifically the GNOME software developed by NOAA.

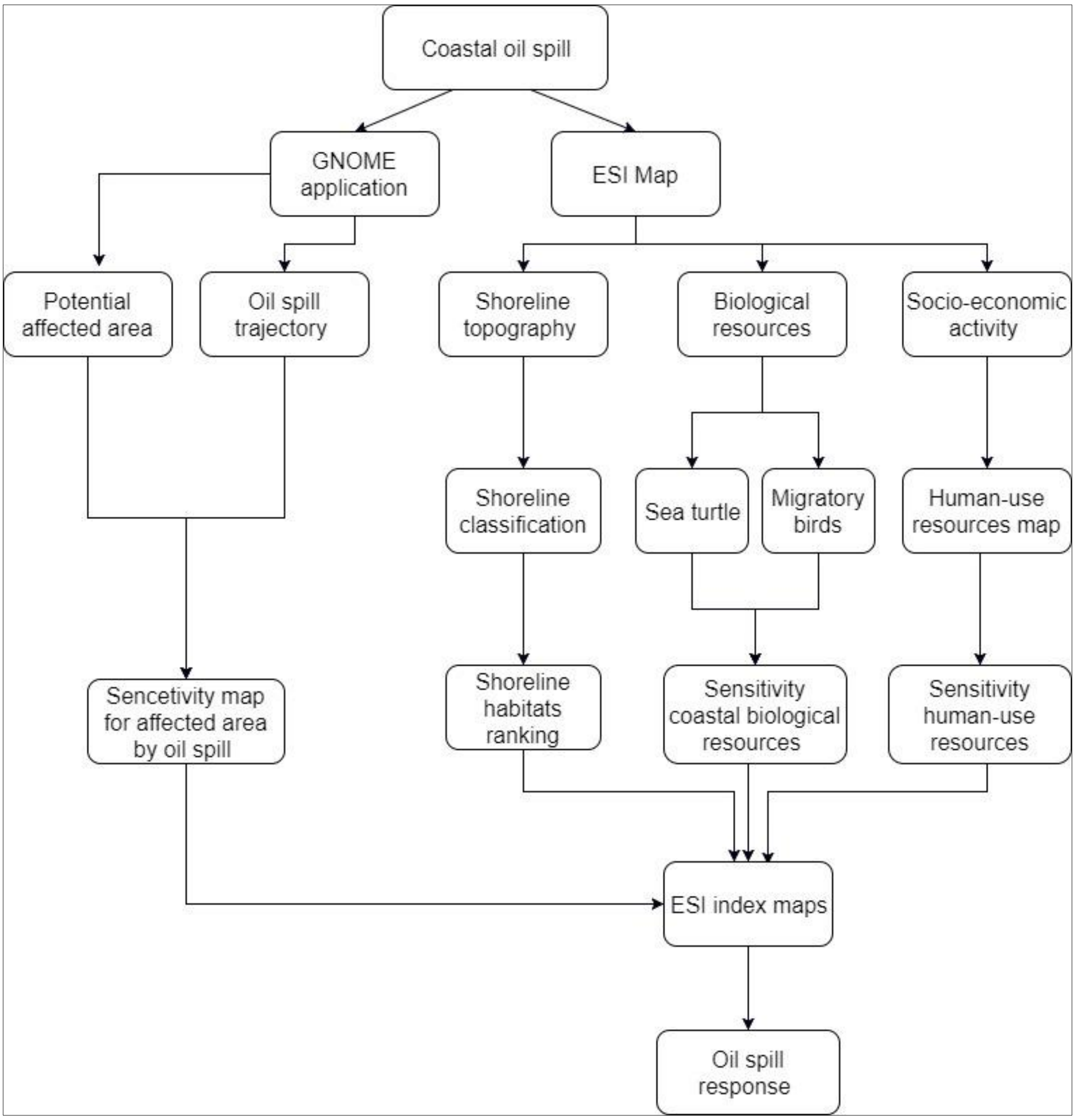


Figure 10 Conceptual models of the sensitivity assessment and shoreline oil hazard mapping framework.

1.4.1 Data collection

The data used to establish oil spill risk levels in this study were obtained from Libyan government agencies such as the Department of Health, Safety & Environment of the National Oil Corporation, Environmental General Authority, Marine Biology centre and National Oil Corporation. These data included oil spill incident information, crude oil production. Other required data, such as oil spill sources, were gathered from reports from local authorities and a fieldwork survey, including information about the amount of oil released from the iron and steel industry, power generation stations, fishing ports and from sewage pipes carrying the waste from garages and fuel stations to the Misratah coast. The coastal habitats and species data were collected from available literature, and annual scientific reports in the protection of the marine turtle program (PMTP) and the United Nations Environment Programme (UNEP).

Data collected remotely were augmented by a fieldwork study of the coast from Dafnia to the West of Buerat in the Southeast of the Gulf of Sidra. Photos were taken during the survey of many polluted areas, documenting the presence of tar balls, which were measured and recorded. Coastal economic and associated activities were observed and recorded.

1.4.2 Identifying, mapping and storage of the coastal resources feature in the ArcGIS software

Coastal and marine spatial planning (CMSP) is a fundamental tool to help achieve effective coastal zone management (Foley et al., 2010). This study applied the CMSP method along the coast to define the coastal resource value and analyse oil spill risk (Frazão Santos et al., 2013; Ehler and Douvere, 2009). After collecting field data and relevant historical maps and information (summarized in Table 1), oil spill simulation software was run and the shoreline classified using data stored and queried in ArcGIS.

In this study, the definition of coastal resource vulnerability depends on gathering of three kinds of information: abundance of species, and conservation status of biodiversity, and oil spill probability according to their proximity to risk factors. The most important environmental components within the boundaries of the case study area are the wetland, the nesting areas for sea turtles (the wide sandy beaches) and feeding places for migrant birds. The salt industry and coastal tourism are the most important socio-economic activities along the coast. Finally, the selection of ecosystem components presented in this thesis is based on their conservation importance as defined by Libyan legislation and international agreements such as The African-Eurasian Migratory Waterbird Agreement (AEWA), Protected Areas and Biological Diversity in the Mediterranean (SPA/BD. Protocol), and Ramsar convention on wetlands.

Table 1 Geographic information system database sources

GIS database	Data type	Resources
Coast type	Fieldwork Historical maps	National Geophysical Data Centre.
Oil spill resource	Maps Reports	Department of Health, Safety and Environment in National Oil Corporation.
Coastal habitats	Maps	Environmental General Authority. Marine Biology Centre.
Bathymetry	Satellite images	United States Geological Survey (USGU).
Oceanography data	Maps	Libya National Meteorology Centre.
Oil infrastructure	Maps Reports	Environmental General Authority. Department of Health, Safety and Environment in National Oil Corporation.
Production area	Maps	UN for the Environment. Marine Biology Centre.
Environmental coastal issues	Maps Reports	Environmental General Authority. Departments of the Environment Public Authority in Municipalities.
Coastal aquifer	Maps Reports	General Authority Water.
Coastal development	Satellite images	Biruni Remote Sensing Centre.

1.4.3 Oil spill simulation

The simulation model (GNOME) provides a useful estimate of the oil trajectory on the sea surface; the application consists of modular programs and a geospatially mapped environment through which oil movement is subject to the actions of winds, current, tides, and diffusion (NOAA, 2002). The outputs of GNOME can be exported as QuickTime movies or Geographic Information System (GIS)-compatible split files that can be loaded and compiled with ArcGIS. Oil dispersion under different conditions is simulated using GNOME to produce hazard maps for the study area by integrating previous information in GIS.

1.4.4 Coastal zone mapping strategies for an oil spill contingency plan

The mapping of environmental sensitivity index (Singkran, 2013., Frazão Santos et al., 2013 ., IMO, 2012) and oil hazard risk (Cekirge, 2015; Oliveira et al., 2013) gives a basis for tactical and strategic plans to deal with oil in the environment.This goal is best achieved if the location of sensitive resources and potential oil spill deposition area are identified in advance so that protection priorities can be established and clean-up strategies selected. By identifying the areas of high sensitivity and high risk, policies can be prioritized and local resources focused for the maximum benefit in environmental protection. These responses need an overview of local infrastructure, reviewed in Chapter 5.

1.4.5 Research aims

In summary, the fundamental aim of this project is to develop a coastal zone mapping strategy for an oil spill that is appropriate for Misratah. Specific research objectives include: (1) the development of a theoretical framework appropriate to coastal zone management, (2) identification of biological, economic and cultural resources and their potential sensitivity to oil spill through a coastal and marine spatial planning approach, (3) assessment of environmental sensitivity to oil spill along the Misratah shoreline, (4) simulate oil spill to determine potential risk areas, (5) the development of a coastal zone mapping strategy for oil responses.

Having given an overview of the research process in the first chapter, Chapter 2 collates information about biological, economic and cultural resources and their potential sensitivities to oil spills. Chapter 3 develops Environmental Sensitivity Index maps for the Misratah shoreline. Oil spill movement in the Libyan Western marine area is simulated in Chapter 4. Finally, Chapter 5 develops a coastal strategic plan for oil spills on the Misratah coast.

Chapter 2: Identification of biological, economic and cultural resources

2.1 Introduction

The study area includes large ports, a range of wetland habitats, nesting areas for sea turtles (UNEP, 2010) and feeding places for migrant birds (Etayeb et al., 2007). The region supports anthropogenic activities including fishing, tourism, harbours, mineral exploitation, salt industry, cultural uses, and the oil and gas industry.

Coastal oil spills, from sources such as tanker collisions, oil loading operations, sewage pipes and fishing activity usually harm coastal habitats and human use activity at two interfaces: foreshore and on backshore, (LDK, 2013). Managing the risk from such spills needs spatially resolved information. For the Misratah district, however, there are (1) limited records on oil spill contamination events, oil production and oil tanker transportation, (2) few studies about coastal resources and their existing condition, and (3) a lack of coastal management infrastructure and coastal resources databases.

Given the gaps in data for assessing oil spill threats to habitats and human uses, the goal of this chapter is twofold: firstly to collate information on coastal resources, including information from a field survey and secondly to lay the groundwork for the coastal sensitivity index and coastal zone management developed in later chapters. The study aims to identify and define the potential negative economic and environmental effects of oil spillage. This chapter focuses on a hierarchy of categories (Figure 12) to develop a base map. The results of this process help planners to maintain amenity values (summer resort beaches), and to preserve historical and archaeological sites within the coastal area (Gilliland and Laffoley, 2008). This initial review of resources can help to identify vulnerable coastal areas and provide specific details to planners to help them set up protection priorities and clean-up strategies (Klemas, 2010; Vandermeulen and Ross, 1995).

This chapter identifies and maps information related to the vulnerability of coastal resources with an emphasis on coastal oil spill risk along the shoreline of Misratah. A four-step approach was followed:

1- Definition of coastal resources value.

2- Identifying coastal resources' importance to local communities.

3- Defining existing condition of coastal resources

4- Determining the connection between coastal and marine spatial planning and oil spill risk analysis.

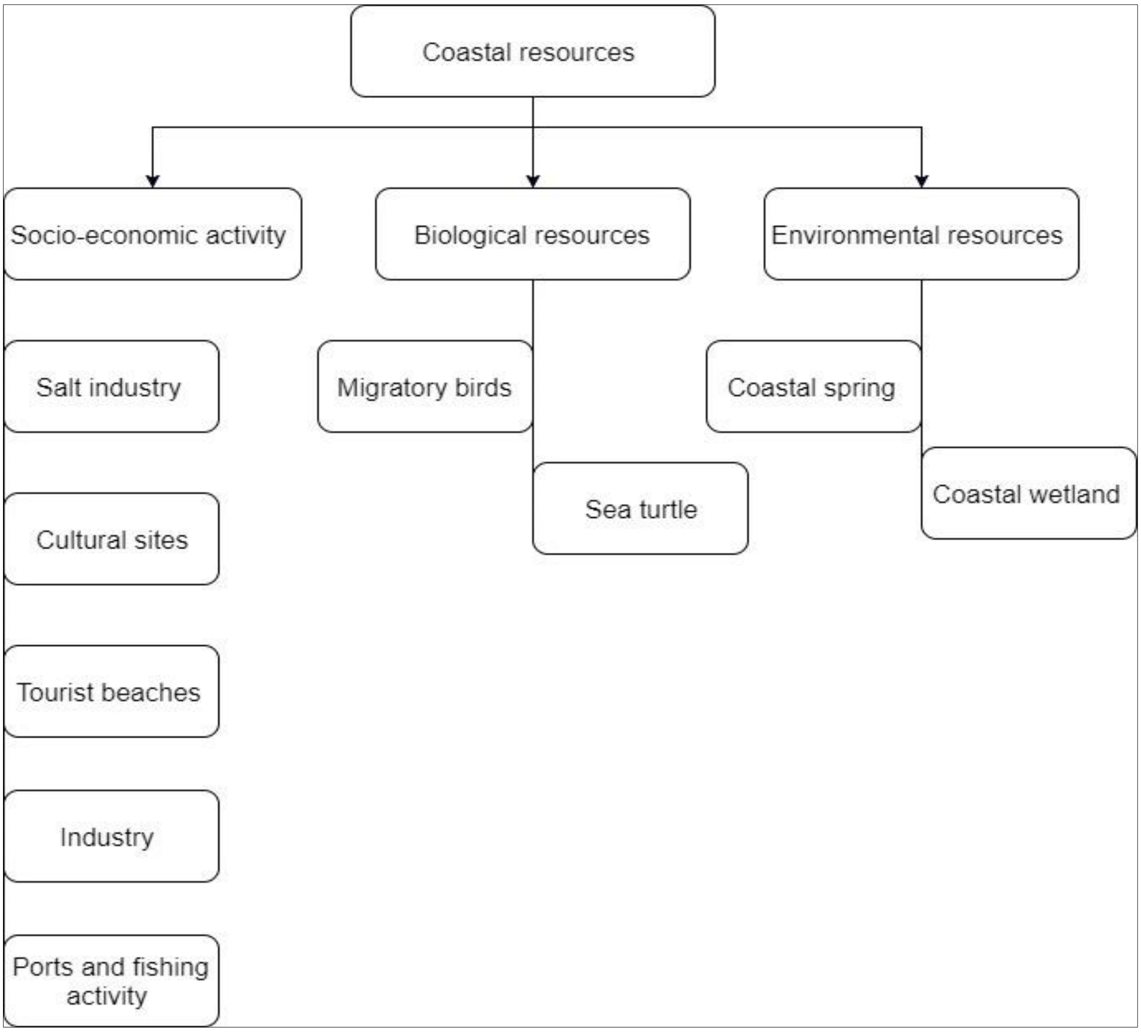


Figure 11 Classification of coastal resource categories described for the Misratah coast.

2.2 Data collection

A coastal database was built to initiate the mapping process, collating data that can be used in the later chapters. Data were obtained from Libyan government agencies such as the Department of Health, Safety & Environment of the National Oil Corporation, Environmental General Authority, Marine Biology Centre and National Oil Corporation (Table 1, Chapter 1). Information on coastal habitats and species was collated from the available literature, and from annual scientific reports in the Protection of the Marine Turtle Program (PMTP) and the United Nations Environment Programme (UNEP). A fieldwork study was carried out in 2014 and 2015, for a total of forty days in both the winter and the summer. The coast was surveyed from Dafnia to the West of Buerat in the Southeast of the Gulf of Sidra. Photos were taken during the survey of any polluted areas, documenting the presence of tar balls, which were measured and recorded. Coastal economic and associated activities were visited and recorded. Tools used to investigate tar ball distribution included GPS, an underwater camera and a square frame of 0.5 x 0.5 m, which was the most frequently use size in Elghirani (1981) and Walda (2002). The survey aimed to map polluted shoreline areas and to survey the beach type/morphology.

The data collected during both fieldwork and satellite images were used to define variations in the environmental parameters and the coastline topography of Misratah. Ikonos imagery was used for initial identification and classification of the different sectors of the study area. However, Google Earth was an essential tool for identifying coastal resources and shoreline type. Afterwards, coastline features were drawn in various colours, and saved as Google Earth (KML). The KML files were exported to ArcMap as shapefiles (Mumby et al., 1995). The mapping tools in ArcGIS 10.2 were used to create layers depicting the overlapping uses of the coastal and marine habitats.

2.3 Methodology and research process

Coastal and marine spatial planning can provide information about specific issues, resources, or areas needing a quick emergency plan (Douvere et al., 2007). Well-researched plans can be used to describe future desired conditions, and provide information and guidance that supports regional action on coastal resources and provides the flexibility to structure the elements of its plans over time in response to what the coastal region wants to accomplish (Douvere, 2008). In this context, coastal spatial planning and oil spill risk analysis are two distinct processes, needed to achieve effective sustainable management of coastal and marine areas (Frazão Santos et al., 2013). These processes play an important role in decision-making on coastal oil spill risk events (Pourvakhshouri and Mansor, 2003). The basis for any coastal management strategy is a synthesis of spatial data on the distribution and intensity of human activities and the overlap of their impacts on the coastal ecosystem (Douvere, 2008).

The development of a database can be used to generate environmental sensitivity index (ESI) maps for the Misratah coast. Coastal resources such as tourism, fisheries, and cultural historical sites, which are often sensitive to oil spill, are represented on the ESI map to help planners address the vulnerability of coastal resources to oil spill with more understanding of coastal processes (Stelzenmller et al., 2013). Hence, the current chapter leads to detailed maps of the oil spill risk potential and coastal resources vulnerability that are crucial to support oil spill contingency plans and decision-making (Abascal et al., 2010).

A coastal resources spatial plan is a fundamental tool to help achieve effective coastal zone management (Foley et al., 2010). The process is essentially open-ended as new or improved information can be fed back into the planning process with a specific application, like an ESI map, being the outcome at any desired point in time (Figure 13). The process starts with the definition of coastal resource value and analysis of oil spill risk, followed by definition and analysis of the condition of environmental and socio-economic resources (Ehler and Douvere, 2009; Frazão Santos et al., 2013). Based on the previous information, scenarios are built to define the potential oil risk areas according to the proximity of an oil spill to the resources.

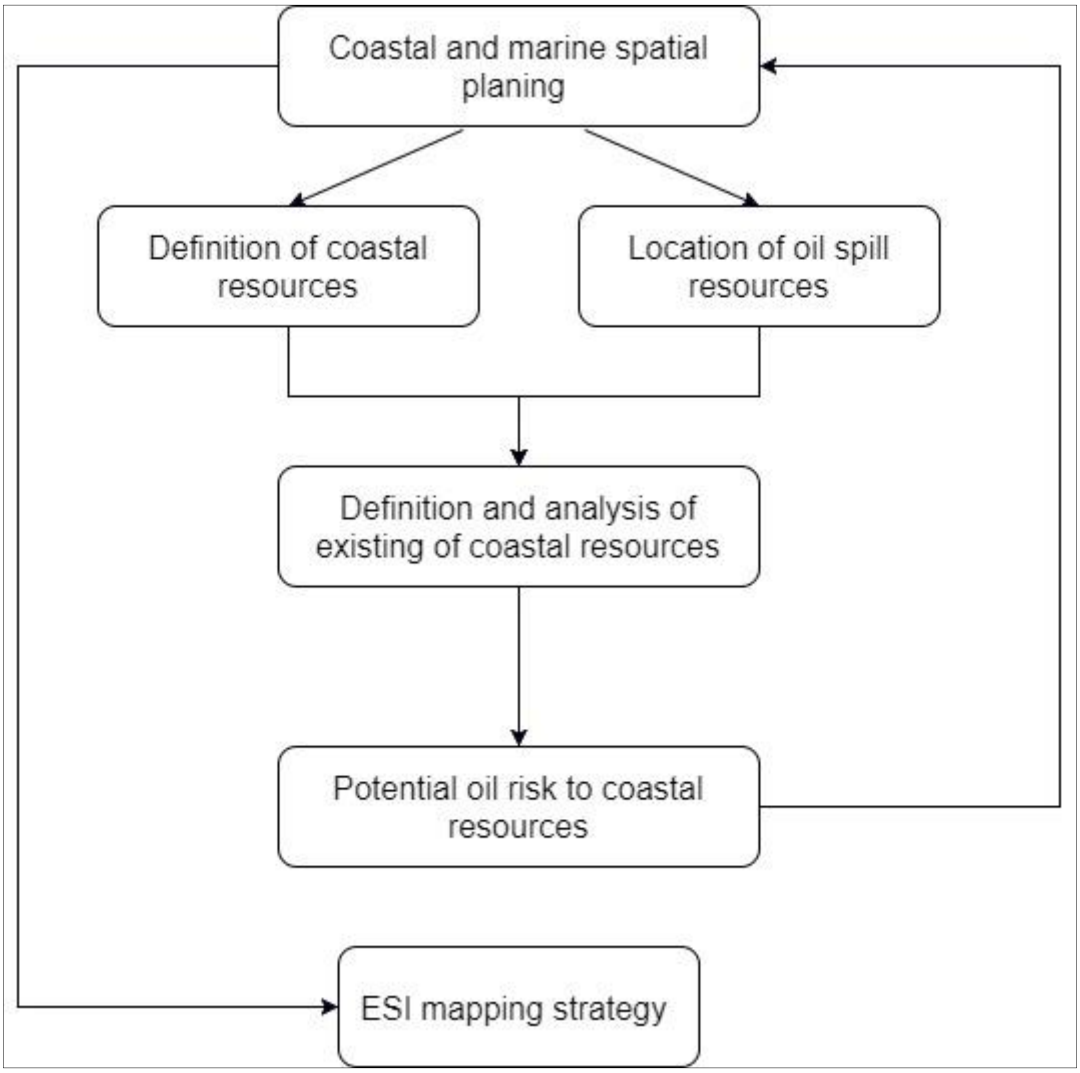


Figure 12 Schematic chart of the process to use scientific information related to ESI methodology within an MSP framework, to identify the spatial pattern of coastal sources and their existing condition.

2.4 Defining of coastal resource values

2.4.1 Human-use resources and their existing relationships to oil spill contamination

The vulnerability of a coastal resource area can be defined with reference the capacity to cope with the impacts of an oil spill (Castañedo et al., 2008). Socio-economic variables are significant factors in coastal vulnerability to oil spills as socio-economic changes occur more often and more rapidly than physical processes change (Szlafsztein and Sterr 2007). Therefore, identifying and analysing human-use resources and their existing condition can help planners to understand, manage, and reduce risk by identifying likely spill scenarios and coastal areas at risk (Oliveira et al., 2013). Moreover, this process can be used to engage a broad spectrum of stakeholders in raising awareness and increasing resilience.

In mapping socio-economic features, the objective is not to identify all human use activity, but to locate the activities that are mostly at risk to be damaged by an oil spill. Fishing, beaches/coastal tourist areas, and the salt industry are at risk due to their locations near potential oil spill sources along the shoreline. The socio-economic activity included in recreational sites along the Misratah coast, e.g. public beaches and summer resorts, and cultural resources, e.g. historical sites, can be impacted economically in the event of an oil spill. Several industries on the Misratah coast are dependent on clean seawater, e.g. water is used for cooling purposes in the iron and steel industries and desalination plants. In these cases, the facilities and processes can be negatively affected by oil ingress into water intakes, possibly leading to contamination of piping systems, which in turn may require that a factory is shut down while cleaning is carried out.

2.4.1.1 Salt industry

Pans are one of the features of salt marshes - Sabkha - (Barbieri et al., 2006) which can be classified into two types: primary pans and channel pans. The former are characterized as a depressed area in the surface of the saltmarsh, while the latter are formed from creek channels (Holden and Council, 2008). The coastal topography in salt marsh areas is formed and maintained through sediment transport processes, involving material carried by rivers, wave, current, winds, and tides (Anthony et al., 2009). The salt industry depends on salt flats, which become salt deposits following evaporation of seawater (Eiser and Kjerfve, 1986). In Libya, most of the salt industry is around the cities of Zwara, Azawia, and Misrata, as well as the Sirte coast and Benghazi region. In particular, in 1985, the Gulf of Sidra area from Misratah in the West to Benghazi in the East produced approximately 11,000 tons of salt annually (Lefond, 1969). The salt industry in the Misratah region is located along the Eastern coast, from Gaser-ahmed to Buerat, covering 170 km (Figure 14.A). In this region there are two types of saltpans: man-made saltpans (Figure 14.B) and natural pans (Figure 14.D). Some saltpans are located on the foreshore, between 1 and 50 m from the water's edge. Recently, the region has been the biggest salt industry area in Libya, spread over a total area of approx. 55 km^2 (Libya Star for Salt, 2017).

Coastal wetlands (Sabkha) are recorded as vulnerable to oil spill because the low wave energy of a salt marsh does not physically remove oil effectively (Pezeshki et al., 1995; Kankara and Subramanian, 2007). Therefore, accidental spillage of oil into the Gulf of Sidra from oil tankers and drilling rigs could significantly impact the salt industry. The risk of oil spill depends on the proximity of the salt industry to oil spill resources such as oil loading platforms in the Gaser-ahmed area. A previous study, conducted in 2012 on coastal lagoons in the East of Libya, showed that a similar environment was already polluted by oil (Alasady, 2012).

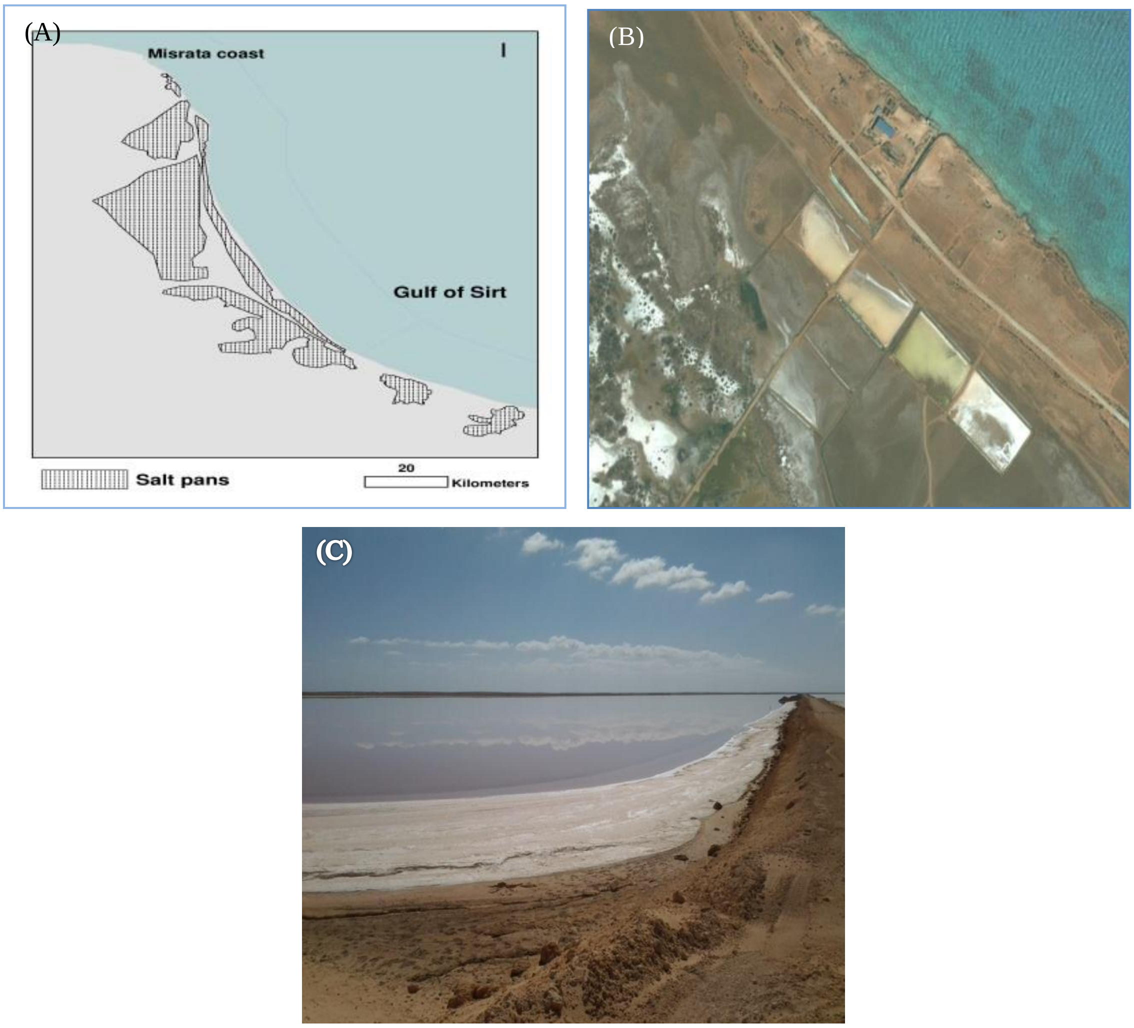


Figure 13 (A) displays the location of salt industry, the map is created in the ArcMap software on the basis of fieldwork data and spot 8 satellite imagery, (B) presents the view of coastal man-made saltpans, (C) saltpan basin in dry season

2.4.1.2 Cultural and historical sites

The coastal area is of great importance to Libya, containing a number of resources that provide economic, environment and aesthetic benefits. Resource conservation requires long-term planning and management to ensure that value is sustained for the future (Daniel Clausen, 2012). Analysis of the condition of cultural and historical sites allows for identification of critical oil spill areas with regions of high archaeological and religious value (Astiaso Garcia et al., 2013).

No database or cultural heritage list is yet available for all local sites of interest. Relevant data was gathered through a literature review of previous technical reports and from interviews with local people during fieldwork surveys in which resource type and geographic location were recorded.

Libya has a number of heritage sites of socio-economic and religious importance along the Mediterranean coast, such as Cyrenaica, Leptis Magna, and Sabratha. The Leptis Magna complex is one of the largest ancient Roman sites in Africa and is on the World Heritage List, along with the old town of Ghadames and the rock-art sites of Tadart Acacus in the Sahara in the south of Libya (D'Urso et al., 2015). Based on archaeological reports, there are a number of cultural sites along the coast, especially on the north coast, which are located close to the shoreline, such as mosques and shrines (Darih) (Figure 15.B).

The sensitivity of the archaeological and religious sites discussed with the local people. The most sensitive archaeological and religious sites are those that are located in the intertidal zone, potentially exposed directly to inundation and spills (Hayes et al., 1992; ORCA, 1997). In particular, sites (Figure 15.A) along the North coast are at risk, due to direct or indirect contact with coastal development and oil pollution, because the North coast is also where oil and gas activity takes place. For example, religious sites on the Zurek coast are located close to the Zurek fishing activity area, which is a potential oil spill sources.

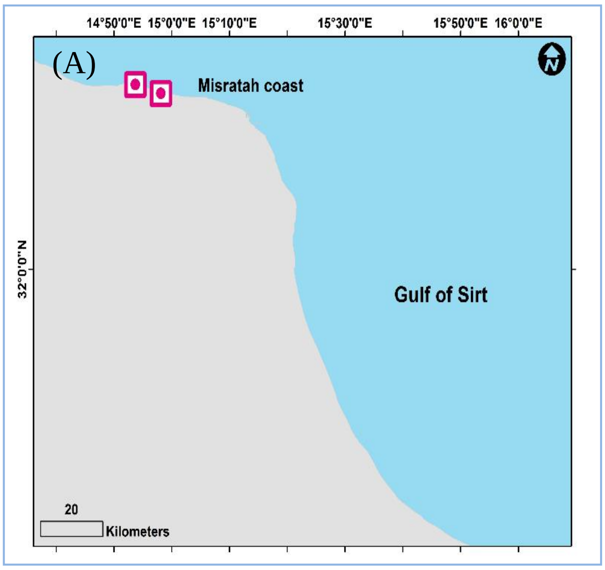


Figure 14 (A) a religious site includes mosques, cemetery and shrines (Darih). (B) Cultural and historical sites at Misratah coast (historical sites locations taken by GPS during the coastal survey study. Historical and archaeological sites are under recorded and have not been fully mapped yet

2.4.1.3 Tourist beaches

Summer resorts and open swimming beaches are important places for coastal tourism. Beach tourism is one of the most important economic activities in Misratah and constitutes a part of the Libyan gross domestic product (Onofri et al., 2013). In the event of an oil spill, tourist resorts suffer income losses and property damages, and need time to clean up. Protection strategies for the coast also have a cost (Novelli, 2011). The Misratah coast includes rocky headlands and wide sandy beaches that attract tourists from all over Libya; most of the coastal resorts are located on protected sandy beaches along the north coast of Misratah, as well as private and public summer resorts distributed on the north coast (Figure 16). Some of the most important locations are Zurek beach, Aljazeera resorts, Altoba open beach, and Alhaded resort, as well as the open sandy beach on the Eastern coast of Misratah.

The tourism industry is under oil pollution pressure due to the proximity of spill sources. For example, Alaman resorts, which comprise 206 villas, attract approximately 10.000 tourists in the summer season (Bady, 2009). The Alaman resort was surveyed during fieldwork in 2014 and tar balls were observed on the sand and rocky shore, possibly reflecting that the resort is situated 20 m from the Aljazeera port and thus, any oil spilt in Aljazeera can easily reach the Alaman shore.

A further important coastal place for tourists is the Alhaded resort, part of the iron and steel complex located in the Gaser-ahmed area. This area is recognized as highly vulnerable to oil spill due to its location near the iron factory and oil loading platform. Additionally, the resort is situated between the two biggest harbours of Misratah city, both of which are potential oil spill sources.

The Altoba coastline is an open beach and one of the most frequently visited places by local people. It might be affected by oil spills due the proximity (1 km) of sewage pipes. Furthermore, there is fishing activity (anchorage) associated with the beaches. Jannat beach has the same issues as Altoba beach, tourism may be harmed by oil spills coming from the Jannat fishing activity and sewage pipes. Therefore, there are oil pollution threats to tourist sites along the Misratah coast due to their co-location with oil spill sources in Gaser-ahmed, Aljazeera, Jannat and Zurek. Some of the summer resorts have been affected by the oil spill and suffer tar ball pollution, which was observed along all coastal areas, but especially on tourist beaches on the north coast.

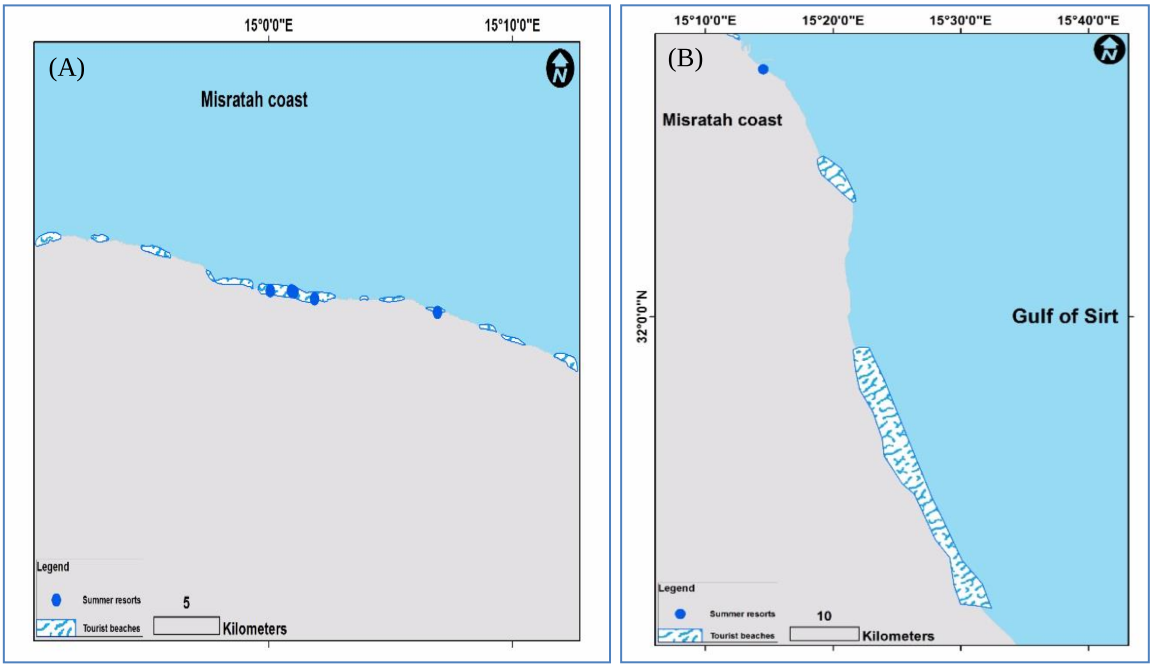


Figure 15 (A) Distribution of tourist beaches (shown by pale blue polygons) and summer resorts (dark blue points) along the north coast, (B) tourist beaches and summer resort along the East coast of Misratah (polygons made in ArcGIS after coastal fieldwork survey to develop geodatabase for the area).

2.4.1.4 Misratah iron and steel complex

The iron and steel complex is considered one of the largest industrial sites in Libya, covering a coastal area of 12 km^2 along the Misratah Sabkha, in Gaser-ahmed on the eastern Misratah coast. The iron industry, power plants, and desalination plants in the complex are dependent on seawater for cooling purposes and also to produce the steam to run the turbines. The iron factory facilities can be affected if oil reaches water intakes, with consequences for piping systems and production processes.

The complex contains a power plant, a desalination plant, a central water station, a oxygen and compressed air plant, a wastewater treatment plant, and a central electric power receiving and distribution station with a total production of steel and iron products of 1,700,000 tonnes per year (Libyan Iron and Steel Company, 2016). The desalination plant was designed to produce 40,000 m^3 water per day to supply the factories and facilities with industrial and drinking water, as well as to contribute to the supply for Misratah city, which is otherwise dependent on groundwater sources, including 90% coming through an artificial river from the Sahara desert (Elabbar and Elmabrouk, 2005).

A particular risk at the desalination plant is that chlorine is added to pumped seawater to protect from biofouling by marine organisms. If the seawater is polluted by oil, chlorine reacts with organic molecules to form trihalomethanes (THM), which are environmental pollutants and potentially carcinogenic. Adhesion of the oil to water tanks and pipes can damage the plant as well (Al Malek and Mohamed, 2005).

2.4.1.5 Ports and fishing activity

Oil spills can cause serious risk to fishing activity; contamination can affect stocks and disrupt business activities by fouling gear or impeding access to fishing sites. There are some publications available from the Environmental General Authority on the Misratah port situation and fishing activity, but fine scale spatial data are limited. This data was aquired during fieldwork in 2013 and 2015 by communication with fishermen and observations of polluted sites, supplemented by technical reports, and available online data about the fisheries in the south Mediterranean region.

Libya has the longest coast of southern Mediterranean states, at approximately 1770 km. It has the second largest continental shelf in the Mediterranean, with more than 250 coastal and marine species recorded in shallow and deep-sea habitats (Fish Base, 2016). Fishing is one of the main resources for the Libyan economy, after the oil and gas industry (Manach et al., 2015). The available data gave domestic fisheries production in Libya in 2004 as 40,827 tonnes, while fish exports in 2006 reached 275 tonnes. In the most recent annual technical reports (The General Authority for Marine Wealth in Libya, 2017) Misratah's fisheries production in 2004 was 643 tonnes. The port at Gaser-ahmed is one of the biggest landing sites in the study area. Table 2 illustrates that there are more than 240 boats landed in the port and fishing production in 2004 was 380 tonnes. However, the fishing productions of Zurek and Aljazeera harbours in 2004 were 155 and 108 tonnes respectively. Both harbours are located in a more protected coastal area, sheltered from wave energy on the western Misratah coast. The two harbours contain 34 and 33 fishing boats respectively (Food and Agriculture Organization of the United Nations, 2016).

Although recent publications on the fishing industry are limited, previous studies and fieldwork observations suggest that the production is decreasing due to stressors such as oil pollution and overfishing (Almabrok, 2004). This section identifies fishing activity and distribution of this activity along the coast (Figure 17) to determine risks to fishing due potential oil spill sources. The industry itself is a pollution risk. The Misratah ports are among the most poorly regulated sources of pollution: most Libyan ports are heavy polluters because of weak infrastructure. There is no emergency plan for oil spill accidents, no clean-up equipment, and structures such as used oil storage are absent, leading to fishermen pouring used oil into the sea.

Oil pollution of the Gaser-ahmed coastal area comes mainly from two sources: oil platforms and shipping (including fishing) activity. The port is the most vulnerable site due to its location beside the industrial coastal area and oil platforms. In the Zurek and Aljazeera harbours, the infrastructure and facilities are poor as well. The remaining fishing activity is characterized as small and seasonal fishing located in small bays or open beaches and representing 44 fishing boats distributed between seven anchorages along the Misratah coast. There are no facilities around these places. The Alkouda and Alroumia anchorages located at the end of the Eastern coast (Figure 17) are the least vulnerable to oil damage due to their location away from other oil spill sources.

Table 2 Distribution of fishing craft at landing sites in the study area, (Food and Agriculture Organization of the United Nations, 2016)

NO	Loading sites	Fishing boats
1	Zurek	**24**
2	Aljazeera	**33**
3	Altoba	**4**
4	Jannat	**12**
5	Gaser-ahmed	**247**
6	Roumioa	**5**
7	Mahaboly	**10**
8	Marzouga	**3**
9	Alkouda	**4**
Total		**342**

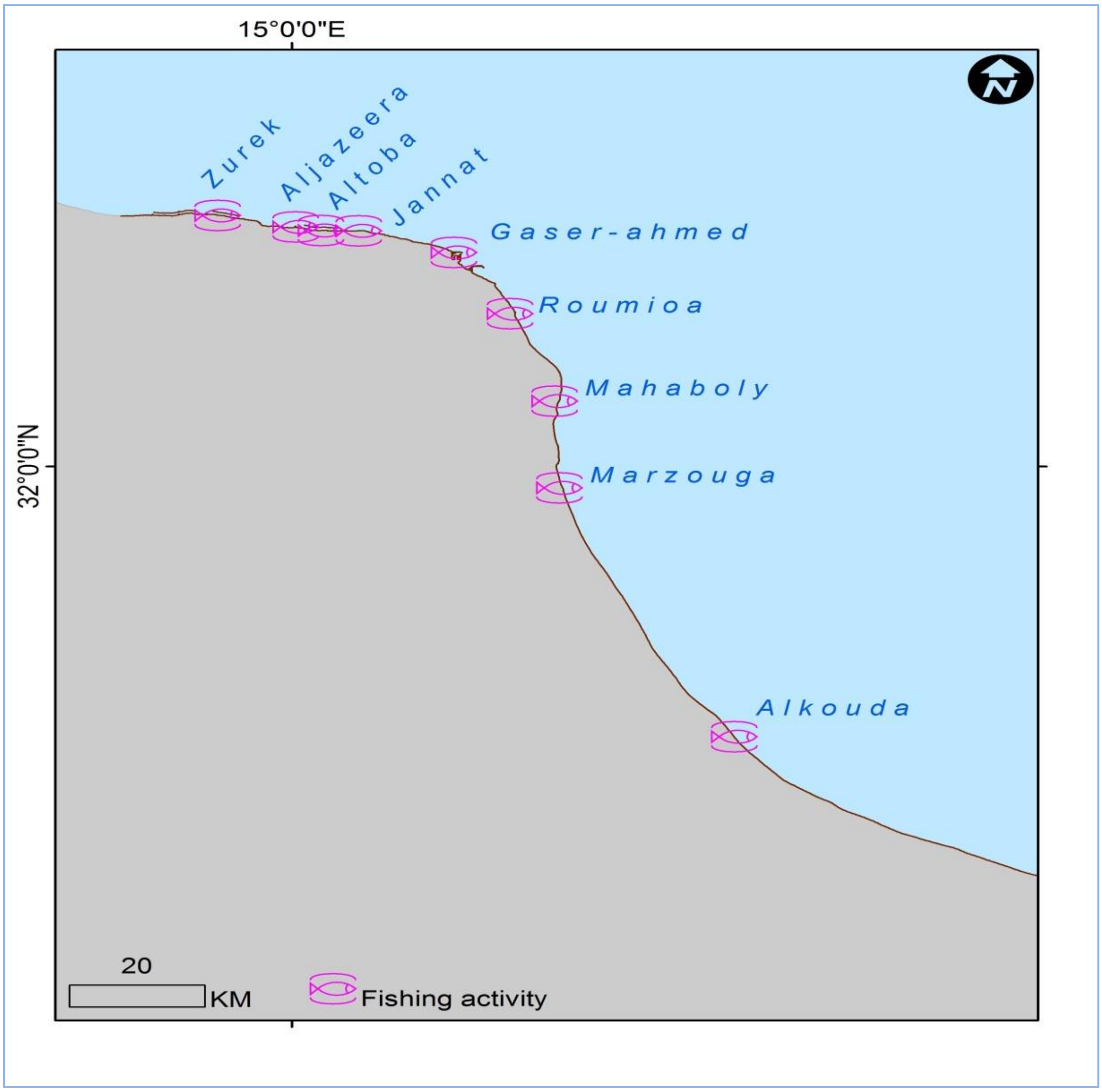


Figure 16 Geographic locations of fishing activity along the Misratah coast. Associated fleet sizes are shown in Table 2

2.4.2 Wildlife resources and their existing relationships to oil spill contamination

The coastal and marine habitats in the Mediterranean are highly diverse; the Libyan coastal and marine environment is recognized as one of the world's 25 top biodiversity hotspots with a large number of endemic species (UNEP/MAP, 2012). Unfortunately, extensive coastal habitats and species data are unavailable. This section therefore focuses on two important biological resources: migratory birds and sea turtles.

2.4.2.1 Sea turtle nesting area

A few studies have focused on the nesting activity of sea turtles on Libyan coast, in addition to annual UNEP reports. The available literature shows (Figure 18.A) some level of nesting activity, mainly concentrated in three coastal sub-regions: (1) the sandy beaches of the Gulf of Sidra, (2) sandy beaches located to the south and the north-east of Benghazi, and (3) on the east side of Libyan coast the area of Derna and Tobruk (Hamza, 2010; UNEP, 2010). The west coast of Misratah, characterized by sandy beaches with a wide intertidal zone, was recorded by UNEP as a sea turtle nesting area. In addition, the Misratah saltmarshes are productive biological systems and are major feeding and nesting grounds for sea turtle and migratory birds (Figure 18.B) (UNEP, 2011). Migratory sea turtles come out of the water onto sandy beaches to dig nests and lay eggs within the period from the end of May to beginning of September (UNEP, 2010). In particular, the Eastern Mediterranean basin of Misratah is used by loggerhead turtles for nesting (Saied et al., 2012). The loggerhead turtle (*Caretta caretta*) is the most commonly encountered species on the coast (Clusa et al., 2013; Laurent et al., 1999). Two other endangered turtles have also been recorded in the West Misratah region: the leatherback (*Dermochelys coriacea*) and the green turtle (*Chelonia mydas*) (Abdulla and Linden 2008). Satellite tracking of sea turtles in the Mediterranean shows the majority of sea turtles tagged on the western coast of Misratah use feeding and overwintering grounds around Greece, with some turtles found around Turkey and the Eastern Mediterranean (Figure 18.C and D) (UNEP, 2011).

Although the western Mediterranean Basin is high in biodiversity, many of its species and habitats are threatened by human activities. For example, the loggerhead turtle is listed as an endangered species by the International Union for Conservation of Nature

IUCN (Öztürk, 2015). In addition, the nesting area has suffered from tar balls (UNEP, 2010). Oil spills will have a different impact on each habitat; for example, turtle nesting areas are more exposed to oil, due their location within the intertidal zone. Oil pollution risk for turtles and their nesting area is greatest during nesting season from May to August. The oil industry and national oil tanker routes in the Gulf of Sidra pose an on-going risk to the survival of Libyan sea turtle populations and their nesting habitat.

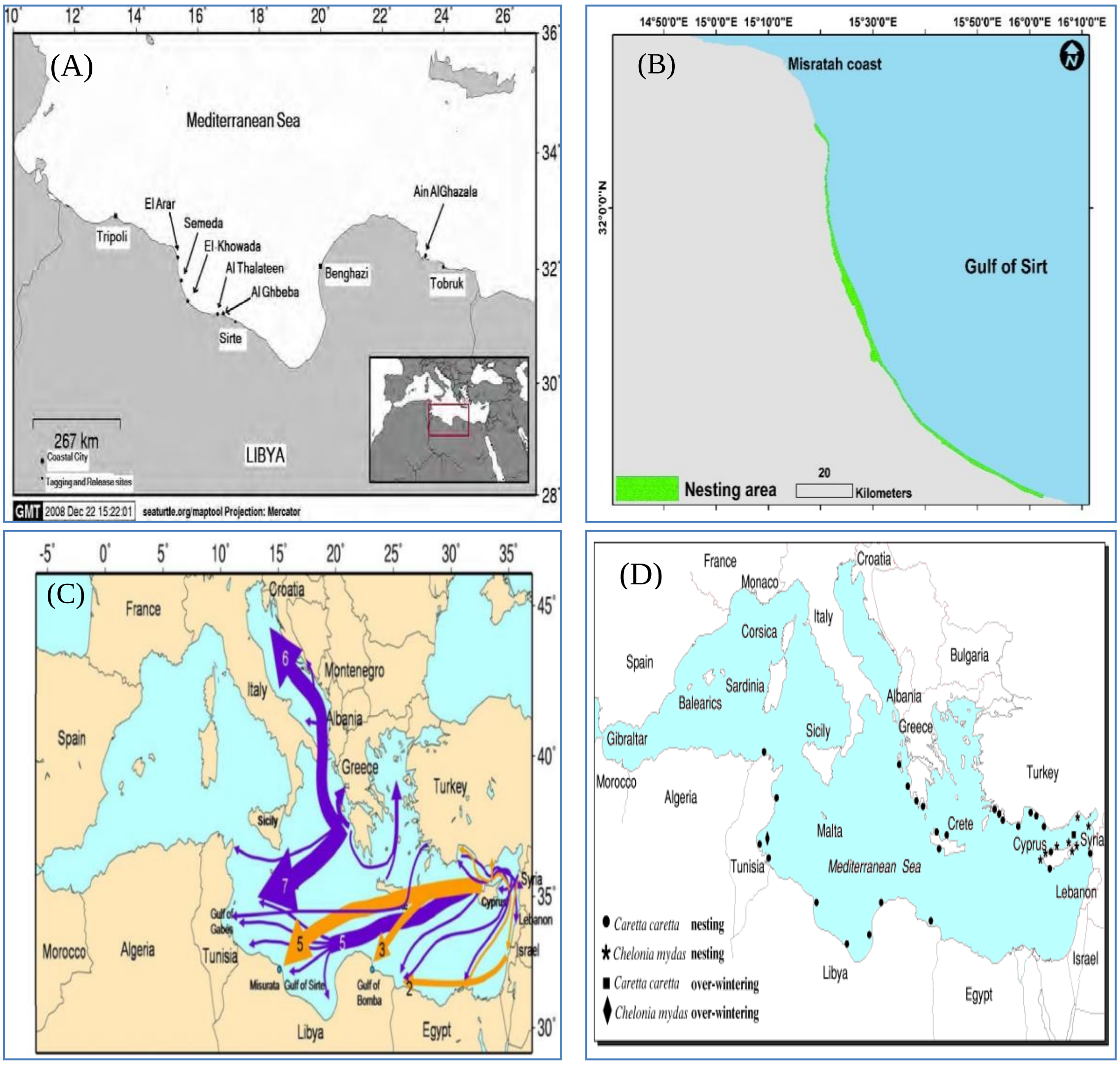


Figure 17 (A) Current turtle nesting areas along the Sidra gulf (UNEP, 2011), (B) nesting area polygon along the sandy beach of the eastern coastline of Misratah, data adopted from Saied et al. (2012), (C) post-nesting migrations of adult female turtles (UNEP, 2011), (D) nesting areas along the Mediterranean coastline (UNEP, 2011).

2.4.2.2 Migratory birds

Mediterranean wetland ecosystems are considered important for water birds, with important areas in Turkey, Italy, Greece, France, Tunisia, Egypt, and Libya (Merken et al., 2015). The Libyan wetlands are resting areas for the passage of migrant birds. In a study conducted by the EGA in 2004, water birds were counted at 83 Libyan wetland sites during the winter season (Figure 19.A). A particularly favour region, the east coast of Misratah, is dominated by a very wild, sandy coastline with a few rocky shores, bordered by saltmarsh (Sabkha) (Laurent et al., 1999). In 2011, the Libyan migratory birds observation team recorded 35,890 individuals belonging to 88 species (Bourass et al., 2013). Several species of birds have also been recorded on the western Misratah coast, visiting this area as nesting and feeding sites during spring (Etayeb et al., 2007).

The coast that migratory birds frequent from September to February stretches from Gaser-ahmed to Buerat, consisting of sand beaches covering approximately 170 km (Figure 19.B) of the eastern coast of Misratah. The coast has important feeding areas for the birds especially on wetland banks and in shallow coastal water (WWF, 2005).

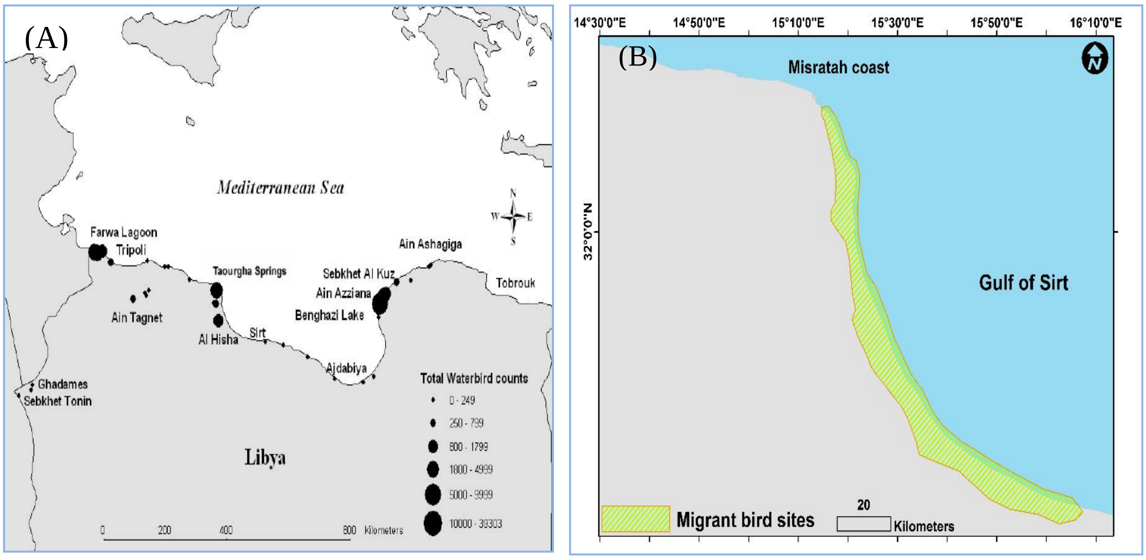


Figure 18 (A) Distribution map of seabird on Libyan coast (Smart et al., 2006),(B) migrant birds feeding and resting area (CSM, 2015), the shapefile of resting area of the migrant birds was generated in the ArcMap as polygon accruing the survey of migratory birds and fieldwork collected data.

The impact of oil spills on the migrant birds is dependent on the spatial distribution of both the birds and oil resources (Begg et al., 2013). Furthermore, identifying potential seabird sites and feeding areas can provide information to planners on how to avoid oil risk to coastal habitats. It is also important to take account of temporal variability due to seasonal migrations of seabirds (Labelle et al., 1982). For instance, a site may be highly vulnerable for only a limited period each year, i.e. September to February.

Although migratory bird sites are not close to oil and gas activity, oil spill simulation maps developed later in this thesis show that there is a potential for oil slicks on the Misratah sea surface to reach the migratory bird areas, due to winds and current action. Oil spill can create stress on coastal and marine environments where birds nest and roost (Islam and Tanaka, 2004). Oil spill impacts are likely to be on birds when they are present at nesting colonies or feeding in nearshore waters (Depellegrin et al., 2010). Thus, migratory birds can be be affected by oil spills, particularly while diving searching for food (Weslawski et al., 1997).

2.4.3 Environmental components and their existing relationships to oil spill contamination

2.4.3.1 Coastal springs

Misratah city is one of the several areas in Libya that faces severe water shortages (Observatory, 2008; Ziadat, et al., 2011). The majority of freshwater comes through a number of huge pipes that transfer water across the desert from the south to the north (UNESCO, 1991). Therefore, this study also identified coastal water value and examined oil spill likelihood and impact on coastal freshwater to create a practical database for shoreline springs to inform the oil spill management policies of the Libyan government. In general, groundwater occurs within six main basins in Libya. These basins consist of several groundwater aquifers with different surface water levels. The Misratah area is located in the Ghadames basin (Libyan water Authority, 2006).

As of the current date, there seem to be no available data on flow from coastal aquifers and springs on the Libyan coast, except a few technical reports on groundwater in the Sahara desert. The previous studies covering coastal fresh water springs are limited as well, as these sites not well known yet by the local environmental authority.

A shoreline survey, conducted during the summer because the coastal springs are completely covered by sea water in the winter, found shoreline springs spread along the North coast from Dafnia to Gaser-ahmed (Figure 20.A). Springs were located in the intertidal area, as little as 1 m from waterline (Figure 20.B and E).

To determine the location of the coastal springs in field surveys, interviews were conducted with local people and the quality of groundwater was assessed by electrical conductivity (EC) meter and PH/ C meter (Table 3; Figure 20.C and D). Groundwater springs are vulnerable to the effects of oil pollution and they are an important resource for local communities, including springs located near potential oil spill sources in the Zurek and Aljazeera areas.

Table 3 Physical features of coastal spring sites

Wall NO	Location	PH	EC	Temperature	Depth	Distance from water edge
1	Gaser-ahmed	8,27	3,25ms/cm	21	3 m	10 M/ in intertidal zone
2	Gaser-ahmed	8,27	3,28ms/cm	21	2 m	20 M in intertidal zone
3	Sour-Saud	8,27	2,80ms/cm	21	2 m	5 M in intertidal zone
4	Jannat	8,27	2,60ms/cm	21	2 m	10 M in intertidal zone
5	Marbat	8,27	2,89ms/cm	21	3 m	5 M in intertidal zone
6	Aljazeera	8,27	2,70ms/cm	21	50 cm	1m/ in intertidal zone
7	Aboroyeh	8,27	3,28ms/cm	21	20 cm	1m/ in intertidal zone
8	Zurek	8,27	3,00ms/cm	21	20 cm	1m/ in intertidal zone
9	Dafnia 1	8,27	2,70ms/cm	21	30 cm	1m/ in intertidal zone
10	Dafnia 2	8,27	2,70ms/cm	21	50 cm	1m/ in intertidal zone

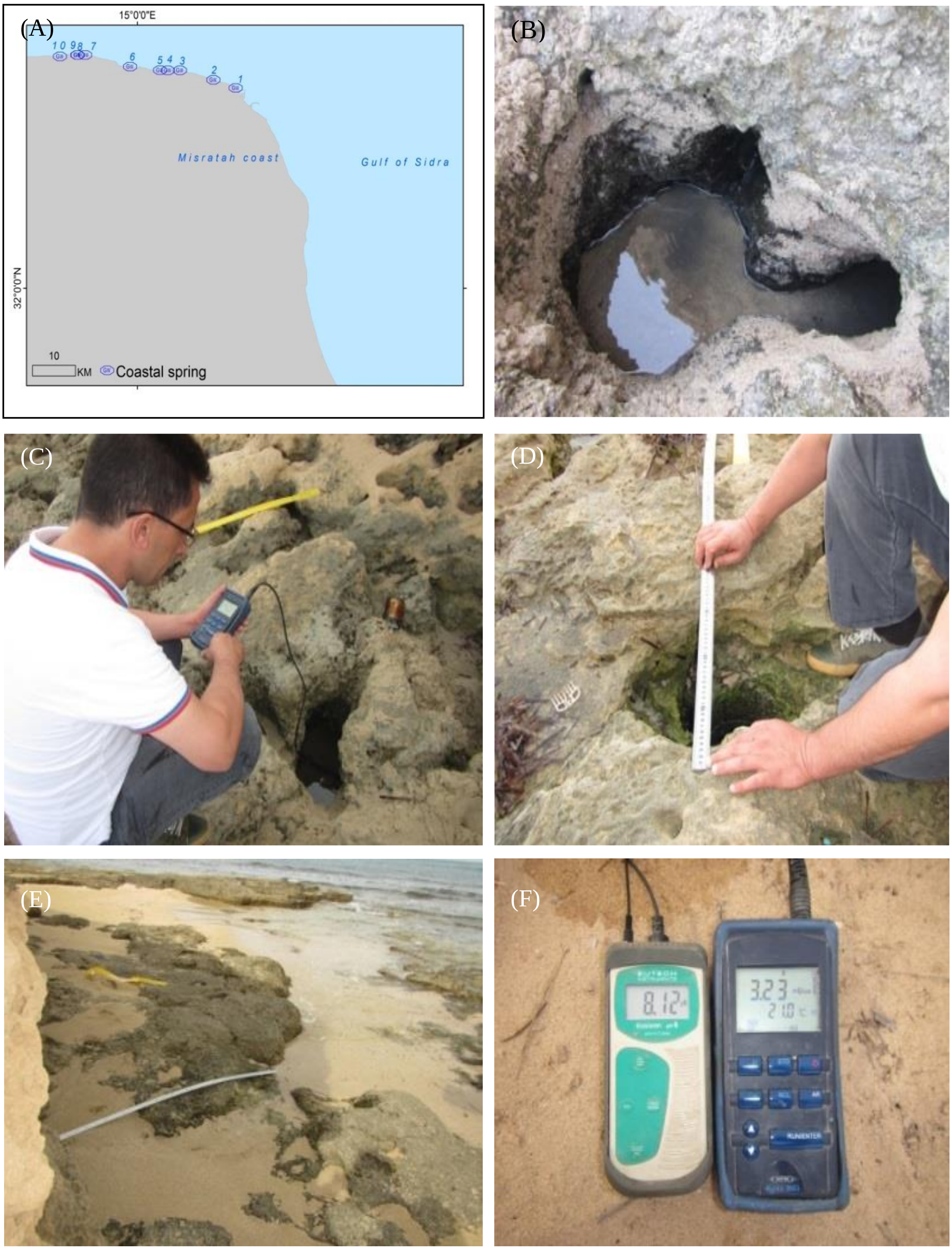


Figure 19 (A) Coastal freshwater spring distribution on the north coast, (B) shows egress of groundwater during the measurement, (C) recording characteristics of the coastal aquifer in summer, (D) measuring the dimension of the well hole, (E) coastal spring located in the intertidal area which is completely covered by seawater and sand, (F) types of equipment used in the field to determine the physicochemical parameters of the coastal spring water,(1) electrical conductivity (EC), (2) PH/ C meter.

2.4.3.2 Saltmarsh (Sabkha)

Sabkha (Subkha), the coastal saltmarsh ecosystem of Libya, is small and limited in overall area (Figure 21.A), but constitutes an important environment, providing coastal habitats for a diverse range of plant and animal species. For example, saltmarshes are feeding areas for seabirds and migrant birds. This saltmarsh is considered as one of the most important coastal resources in the area, and is recognized as a protected area in the RAMSAR protocol. The Sabkha represents the lowest topographic depression in Misratah region and contains two features, salt flats and vegetation areas (Figure 21.B and C) (El-Hinnawy and Cheshitev, 1975). The Sabkha is flooded in the wet season by seawater seepage or seawater flood (Basyoni and Mousa, 2009). In the Sabkha area there are two different zones; low topography, like a small lake, is generally located near the coastline and is covered by the sea in winter, relatively higher elevation areas of Sabkha are characterized by patches of vegetation at the border of the Sabkha (Figure 21.D).

The Eastern coast of the Misratah region includes broad areas of supratidal salt flats, termed ‘dry basins’ in the summer, but becoming wet in the winter (Stivaletta et al., 2009). These areas occur behind wide sandy beaches and coastal dunes in relatively low topographic areas (Galil and El-fergany, 2011). The Misratah Sabkha is situated in a coastal Sabkha plain over an approximately 1500 km^2 stretch along the Gulf of Sidra on the western coast of Misratah extending from north to south: 170 km from Gaser-ahmed to Buerat.

The Sabkha ecosystem has ecological value because it hosts a number of migrant birds and sea turtles during seasonal migrations and nesting. This sensitive area is exposed to coastal disturbances and oil spill pollution due to its location and environmental situation. The Sabkha coast is located in a semi-closed sea (Gulf of Sidra) and sea energy is low compared to the open sea on the north coast of Misratah in the Mediterranean Sea. The Sabkha coast suffers from tar ball pollution as material tends to accumulate rather than be dispersed.

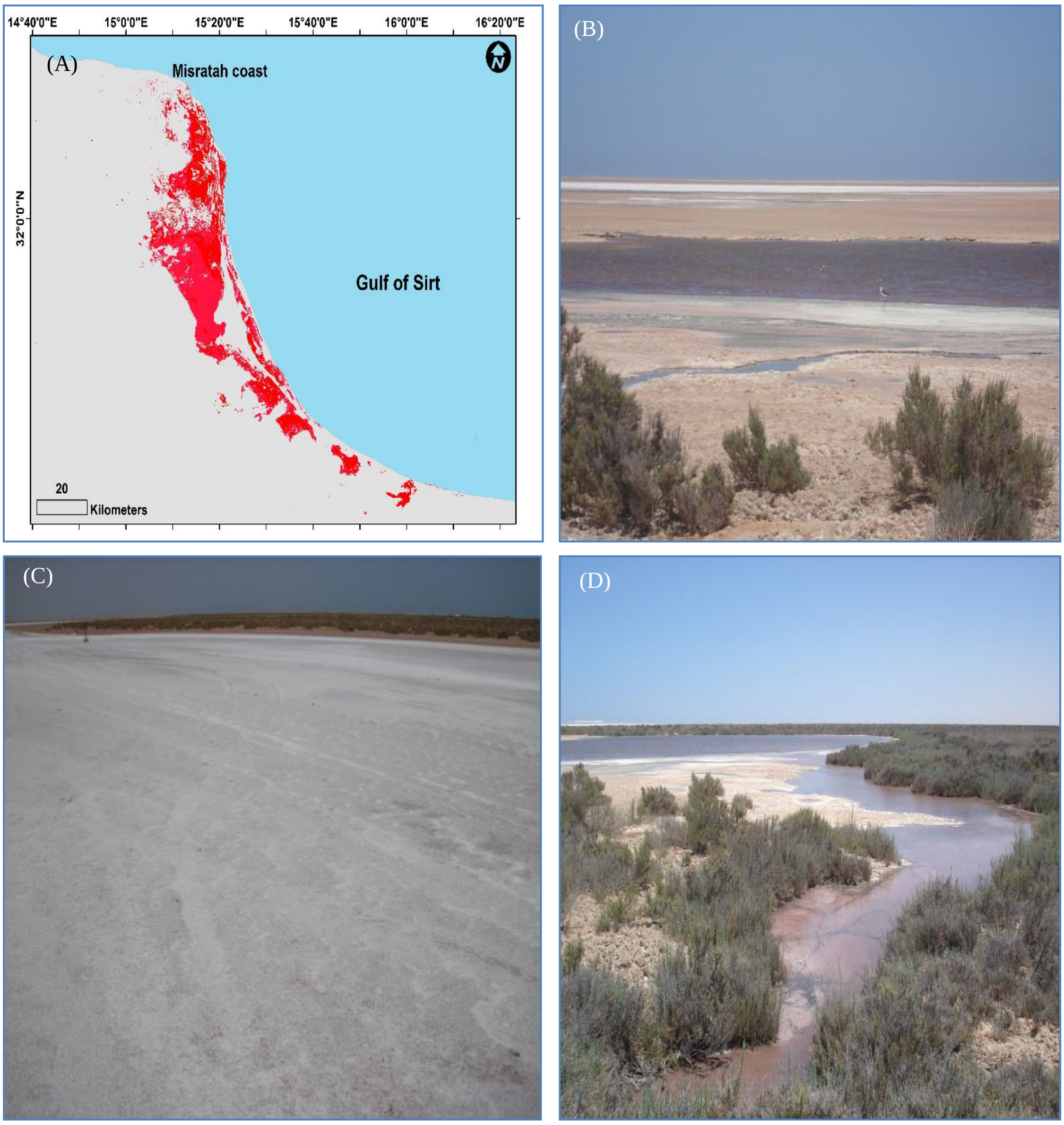


Figure 20 (A) Distribution of Misratah wetland. The map is derived from spot 8 imagery, (B) sabkha vegetation, (C) saline pan, (D) sabkha during a flooding phase in winter reason.

2.5 Conclusion

Coastal management and conservation of the habitats and resources on the Misratah coast require synthesis of spatial data on the distribution and intensity of human activities and the overlap of consequent impacts on the coastal ecosystem. The main purpose of identifying the features of the Misratah coast is in preparing a framework for coastal zone management of areas sensitive to oil spills. The coastal features were mapped in GIS to generate one map for each variable and features were represented as polygons and points to show the spatial distribution of biological resources.

Because little research has been conducted on mapping and coastal resource values, with limited data and publications for the Misratah region, this study uses available coastal and marine information to create a database for coastal sensitivity index maps along the coast, acting as a reference for how to protect and manage coastal resources in the Misratah coast and the rest of Libya. Moreover, this work highlights the value of natural coastal resources such as the salt industry and coastal groundwater quality to the Misratah population and its economy.

The Misratah coast has multiple uses including fishing, tourism, harbours, mineral exploitation, the salt industry, and cultural uses, each of which has a different economic importance. The coast contains two distinct shore regions; the north coast is defined by sandy beaches with narrow rocky shores and most of the human activities take place on the north coast, including fishing, coastal tourism, industry, ports, oil platforms, oil storage, and coastal development. In contrast, the Eastern coast is mainly composed of wetland coasts.

The Misratah coast has suffered from two types of oil spill: (1) onshore oil spill coming from urban areas and flowing to the coast, (2) oil spills coming from the offshore oil industry and tanker traffic. The Sabkha ecosystems are under pressure due to increasing human activities such as urban development, tourism-related activities, and a different pollution type from iron and steel industry located in the Gaser-ahmed Sabkha, as well as an illegal landfill. This chapter identifies specific economic and ecological resources at risk from oil spill. The potential sources of oil in the marine environment are also shown to be diverse, with major spill risks existing alongside persistent oil pollution from coastal towns and ports.

Chapter 3: Assessment of coastal environmental sensitivity to oil spill

3.1 Introduction

The density of marine traffic, especially oil tankers, in close proximity to the coast, in addition to offshore petroleum exploration and production platforms, make the Libyan coast a high-risk area for oil spills. About 20% of global oil transportation passes through Libyan waters (Abdulla and Linden, 2008). Libya has ten offshore oil fields and two oil platforms in the West, along with seven oil platforms spread along the coast (National Oil Corporation of Libya, 2016). Additionally, minor oil spills from sources such as fishing ports and factories are a further source of coastal pollution. Oil spills can cause substantial damage to the Libyan coast and marine ecosystems, causing biodiversity loss and economic impacts on fishing and the tourist industry (Elfallah and Boargob, 2005).

The purpose of this chapter is to assess the oil spill risk faced by the Misratah coast and to present information on shorelines using environmental sensitivity index (ESI) maps (Petersen *et al.*, 2002). Mapping of ESI values is a fundamental step in supporting coastal zone management, identifying segments of shore by their capacity to recover after an oil contamination event. An ESI atlas summarizes shoreline sensitivity and supports coordination and planning of responses to oil spills (Al Shami *et al.*, 2017).

Perhaps reflecting the diverse coastlines and climate of the United States of America where ESI maps were developed, the methodology has proved applicable worldwide. Many previous studies have used the ESI for oil spill sensitivity maps. Sometimes a regional approach is suggested as local shore types do not map exactly or explicitly to the existing ESI categories (Aps *et al.*, 2016; Oliveira *et al.*, 2014). A diversity of shore types has been categorized for regions relevant to the likely conditions of the Libyan coastline. Adler and Inbar (2007) concluded that the Israeli coastline was generally of moderate sensitivity to oil spills due to the morphology and exposure of the predominantly beach-dominated shoreline. Al-Hargan (1997) created a coastal information system for the Qatar coast using GIS and remote sensing. Large sections of the Qatar coast were identified as salt flats (Sabkha) backed by marshes; these areas have a relatively high environmental sensitivity index values as oil can have large and long lasting impacts. The sensitivity of salt marshes (up to 14 m inland from the shoreline) was clearly identified from advanced visible infrared imaging spectrometer (AVIRIS) data gathered over the coast of Louisiana following the Deepwater Horizon spill (Khanna *et al.*, 2013).

Direct evidence of oil pollution on the Libyan coast has mostly been inferred using studies of tar balls, the distribution of which can be quite variable in space and time. Al-Ghirani (1981) found a total weight of tar balls on the Misratah shore of around 646 g m^{-2}. Walda (2002) recorded an average 24 g m^{-2} of tar balls in the same region, whereas Maitieg (2004) suggested that the highest average tar ball concentration was 134.29 g m^{-2} along the North coast of Misratah. In a seasonal study of water samples from coastal lagoons on the eastern coast of Libya Al-Asadi (2012) found the highest levels of oil pollution in summer, with values exceeding 10 $\mu g\ L^{-1}$ total petroleum hydrocarbon, indicating significant oil pollution.

Beyond reports of environmental contamination, there are few studies on the risks and sensitivity of the Libyan coast. This reflects a wider discrepancy between the extent and detail of northern and southern Mediterranean research that has been highlighted previously (*e.g.*, Daffonchio *et al.*, 2013). Some preliminary results on the satellite-derived distribution of slicks along the Libyan coast have been reported by Eljabri and Gallagher (2012). A detailed study of shoreline sensitivity is, however, lacking. The current chapter therefore describes the coastline around the significant industrial port of Misratah, Libya.

3.2 Methodology

Field data collections were carried out on Misratah shores in 2014/2015. Handheld GPS devices and digital cameras were used during the survey to record and document details of shores. The whole study area was surveyed over a period of twenty days, from the high cliffs at Dafnia on the Northern coast to the sandy beaches of Buerat, to the Southeast in the Gulf of Sidra. The data collected from each surveyed sector included the existing environmental settings and characteristics such as shore type, available species, presence of tar balls or oil pollution, other pollution sources and socio-economic activities. Ikonos imagery was used for initial identification and classification of the different sectors of the study area. Google Earth was also used for identifying coastal resources and shoreline type. Coastline features were marked up and saved as KML files in Google Earth before import into ArcMap (Mumby *et al.*, 1995). Coastal resources are ranked and colour-coded with the standard ESI palette, based on sensitivity to oiling (Udoh and Ekanem, 2011).

The study area covers 248 km and includes various coastal types, such as coastal salt marsh, rocky shores and sandy beaches. Additionally, the impact of oceanographic energy to oil spill movement is different in each part of the world. The ESI classification of the shoreline was based on four main categories of environmental characteristics: (1) the degree of shoreline exposure to wave and tidal energy, (2) permeability and shoreline oil capacity, (3) shoreline slope (Aps et al., 2016) , and (4) the level of biological diversity and productivity of the affected shore (Mahapatra and Ramakrishnan, 2015; ORCA, 1997). Rankings of shoreline environmental sensitivity to oil spill are assigned on a scale (1–9). Shorelines that are put into highest ranks on this scale are most sensitive to oil spill considering the overall combination of environmental characteristics (Aps et al., 2016). For example, ESI 1 refers to shorelines with the lowest susceptibility to damage by oil spill because oil cannot penetrate bedrock (as found on exposed rocky shores), while ESI 9 refers to shorelines that are most likely to be affected by oil, such as salt marshes or sea turtle nesting habitats (Gundlach and Hayes 1978).

3.3 Results and discussion

The Misratah shoreline sensitivity to oil was determined according to the NOAA ESI categories (2002). However, the concept of mapping coastal environments and ranking them on a scale of relative sensitivity originated with Michel et al. (1978). Each ESI ranking is represented by a different colour on the created ESI map; in many sectors the shoreline may have two different classifications. These multiple classifications are represented on the maps by double lines. For example, in the Dafnia section, the shoreline is represented with two coloured lines to represent the exposed tidal flats and exposed rocky shores in the same coastal area. The ESI is considered a quick reference for oil spill responders and coastal zone managers and can be used to identify sensitive coastal sectors before any spill occurrence (Tri et al., 2015).

The shoreline sensitivity ranking in Table 4 goes from ESI 1, representing least sensitive to oil, to ESI 9 which represents the most sensitive areas, reflecting influences of relative exposure to wave and tidal energy, shoreline slope and substrate type (Sowmya and Jayappa, 2016). The shoreline sensitivity map (Figure 22 A, B) classifies the study area to eleven rankings on the ESI scale (Figure 23). The resulting ESI approach highlights the occurrence of vegetated low banks, ranked as the most sensitive shoreline to oil spill, while the exposed rocky shores ESI1 have the lowest sensitivity to oil spill. The ESI ranking enables responders to prioritise the shorelines in terms of protection. The ESI types were classified in the study area as follows:

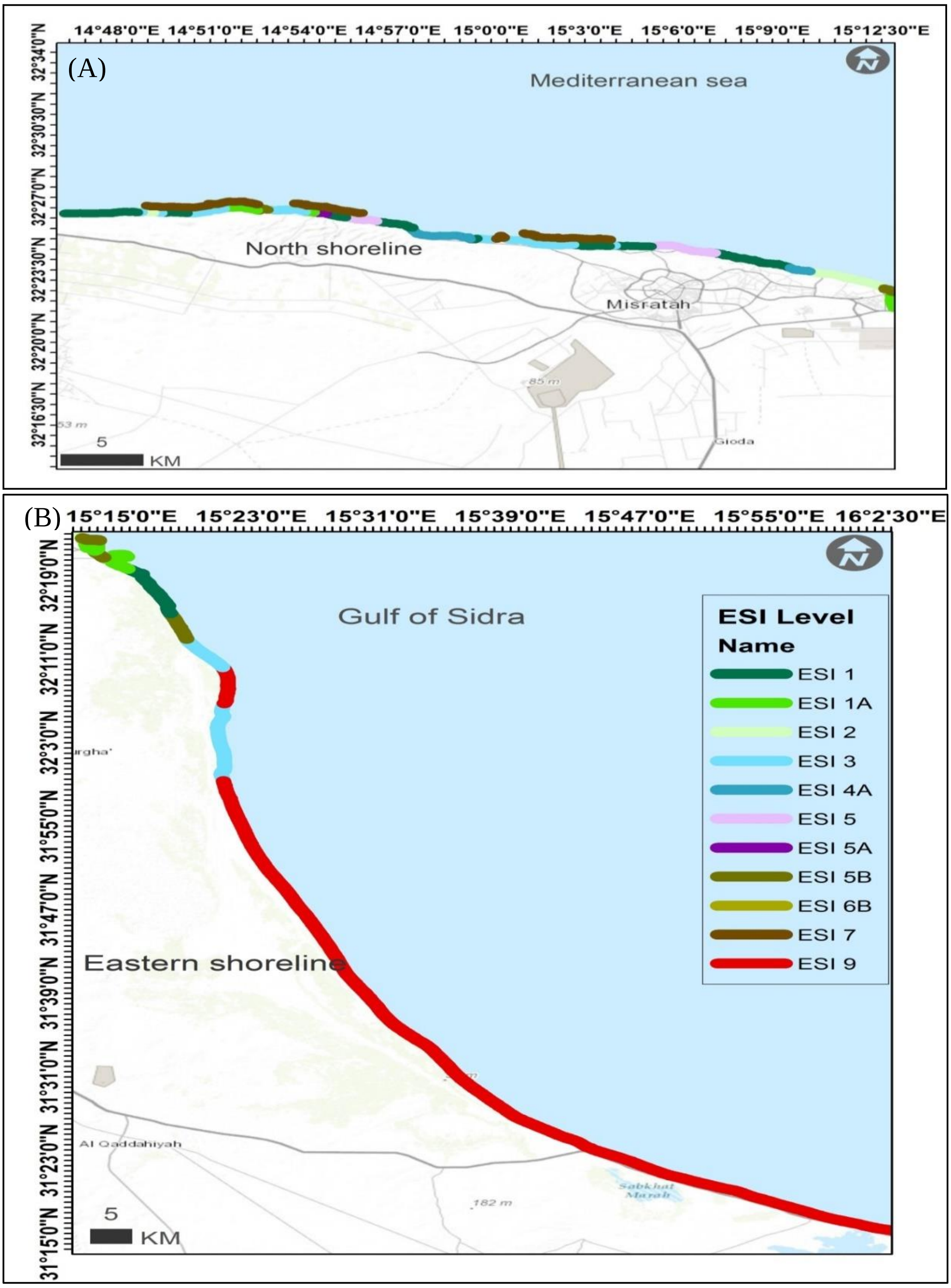


Figure 21 ESI shoreline classification maps for Misratah shoreline, Map (A) shows the north and (B) the eastern coast. Habitats with red colour ESI 9 (vegetated bank shores) were the most sensitive habitats for oil pollution, whereas habitats with green colour ESI 1 (for exposed rocky and exposed man-made structure shores) were the least sensitive habitats. An expanded explanation of ESI codes by sector is given in Table 4.

.

ESI 9 Vegetated low bank: this shoreline type is only along the Eastern coast, covering 128.13 km of study area. The shoreline is considered very highly sensitive due to biodiversity value, reflecting the saltmarshes and coarse sandy shore that contain sea turtle nesting areas and sites for migratory birds. In the event of oil near to the shoreline, this could deposit along the high tide line into the saltmarsh. The oil is likely to persist as it can soak into the habitat and wave energy for dispersing slicks is low due to the relatively sheltered nature of the coastline. The ESI 9 category was used rather than ESI 10a (salt marshes) as the use of 10a seems to better describe areas where the marsh directly enters the sea rather than the more complex setting of sandy banks backed by marshes seen on the eastern coast.

ESI 7 Exposed tidal flats: are present on the northern coast in an area where wave activity is relatively high and cover 15.51 km of the shoreline. The intertidal flats appear rich in invertebrate species, and can emerge in summer time when wave energy is low and sea levels are generally lower. Oil deposited on this area and on this type of beach might remain for a long period, particularly in summer months.

ESI 6 B Riprap beaches: this shoreline has the shortest extent, covering 400 m. Riprap is a man-made wall made of large boulders or concrete blocks with a moderate to high abundance of species such as green and brown algae, oysters, barnacles, limpets and other marine snails. This shoreline category has medium-high sensitivity. Riprap is used as a coastal defence so it is often subject to high wave and tide energy. In an oil spill, oil might penetrate deeply between the boulders. Biological resources could be damaged by oil spill and the probability and frequency for hazard by oil spill is high because most riprap beaches were built near ports and sites such as harbours and anchorages. Most of these types of shores are located on the northern coast.

ESI 5 B Boulder shores: this is an uncommon beach type covering 10.29 km, found both on the eastern coast, and on the northern coast at Dafnia. The shore type is formed from a range of small and large boulders. Oil can penetrate deeply between rocks, potentially remaining for some time.

ESI 5 A Irregular protrusions of rocks through sand: This is a rare type in the region, representing less than 1 km of the Misratah shore, most of which is 670 m of irregular protrusions of rocks in the Zurek coastal area. The sensitivity of this type of beaches was based on the potential for medium to high oil penetration.

ESI 5 Mixed sand and gravel beaches: This type of beach is not common in Misratah coast, covering 5.45 km of the shoreline. Fauna and flora abundances are low due to sediment mobility. Oil spills onto this type of beach sediments might be end up deeper than 50 cm, making these beaches difficult to clean (Hayes, Michel, and Noe, 1991).

ESI 4A coarse sand: this classification is found on the Eastern coast of Misratah, and covers 4.81 km of the shoreline. Waves and current are not strong in the Gulf of Sidra. Oil persistence may be high and coastal habitats and species such as nesting turtles could be at risk from oil spills.

ESI 3 Fine to medium sandy beaches: this category represents the second most common shore type in the Misratah region, found on 31.55 km of the shoreline. The major feature of this shore type is that it is only semi-permeable to oil and, therefore, oil persistence can be short-term before removal by wave action or clean-up activity on the beaches. The abundance of organisms in these habitats is relatively low. However, organisms such as crabs, amphipods and near shore shellfish could be affected by oiling.

ESI 2 Exposed wave cut platform: A wave-cut platform or wave-cut benches are the narrow flat area often found at the base of the sea cliff. This shoreline type is found along 5.31 km of the shoreline. Oil might remain on flats in a sheltered area and an oil spill would damage the habitats on the rocky shores.

ESI 1A Exposed manmade structure: On smooth artificial sea walls the species abundance and diversity is low. This shoreline type is located around factories and ports and some coastal tourist areas, representing 19.72 km of the shoreline. Typically sea walls are a coastal defence and are vertical or near-vertical. These features mean that oil is unlikely to persist and may even be directed offshore as waves are reflected from the sea wall.

ESI 1 Exposed rocky shores: the major area for this type of shore is located near Dafnia, Marbat and Sour-Saud on the northern coast, covering 27.18 km. This shoreline is exposed to open sea and these shores are steep and exposed to high wave energy. They contain few species. This shore can be self-cleaning with wave reflection keeping most of the oil offshore (Hanna, 1995).

Table 4 Environmental sensitivity index (ESI) descriptions for each category found on the Misratah coast, including sectors where each shore type is found and total length for each shore type.

ESI level	Colour code	Shore type	Main feature	Sector location	Length Km
ESI 1		Exposed rocky shore	Exposed to open sea and impermeable to oil	Gaser-ahmed, Jannat, Marbat, Dafnia, Zurek Aboroyeh and Aljazeera shores	27.18
ESI 1A		Exposed man made structure	Exposed to large wave at open sea sector	Gaser-ahmed, Zurek and Dafnia shores	19.72
ES 2		Exposed wave cut platform in bedrock	Exposed wave energy and impermeable to oil	Dafnia and Sour-Saud shores	5.31
ESI 3		Fine to medium sandy beaches with mostly moderate sloping	Low to medium penetration	Dafnia, Zurek, Aljazeera Alarar and Marbat shores	31.55
ESI 4A		Shorelines with coarse sand and mostly sloping	Medium penetration to oil spill and located at semi-closed beaches	Sour-Saud and Aboroyeh shores	4.81
ESI 5		Mixed sand and gravel beaches (cliff shore)	Medium to high permeability to oil spill	Zurek and Jannat shores	5.45
ESI 5A		Irregular protrusions of rocks through sand	Medium to high permeability to oil spill	Zurek shore	0.67
ESI 5B		Boulder shore	Deep penetration of oil	Gaser-ahmed, Zurek and Albonta shores	10.29
ESI 6B		Riprap beach	Deep penetration of oil	Aljazeera shore	0.40
ESI 7		Exposed tidal flat	High biological productivity	Dafnia, Zurek and Aljazeera shores	15.51
ESI 9		Vegetated low bank	High biological productivity	Buerat, Alromia, Marzouga and Alkouda shores on the Eastern coast	128.13

ESI 1 – Exposed rocky shores

ESI 1A- Exposed man made structure

ESI 2 – Exposed wave cut platform

ESI 3 - Sandy beaches

ESI 4A – Shorelines with coarse sand and mostly sloping

ESI 5 – Mixed sandy and gravel beaches

ESI 5A – Irregular protrusions of rocks

ESI 5B - Boulder shore

ESI 6B Riprap beach

ESI 7 – Exposed tidal flat

ESI 9 - Vegetated low bank

Figure 22 Examples of different Misrata shoreline types by Environmental Sensitivity Index (ESI) category. (1) ESI 1 at Dafnia with vertical rocks exposed to the open sea. This type of shore is impermeable to oil and has relatively high natural clean-up ability. (2) ESI 1A artificial shorelines. (3) ESI 2A shoreline in the Dafnia and Sour-Saud shores. (3) ESI 3 medium fine sandy shores found in Dafnia, Zurek, Aljazeera and Marbat in the north, and Alarar shores in the eastern coast. (4) ESI 4A shoreline in Sour-Saud and Aboroyeh shores of the north coast. (5-7) shorelines distributed along the north coast. (8) ESI 5 shoreline at Zurek in the north and Gaser-ahmed and Albonta shores in the East. (9, 10) ESI 6B and ESI 7 gives an idea about high sensitive shoreline to oil spill which are located on the north coast. (11) ESI 9 shorelines of vegetated low banks along the eastern coast (see Figure 22 for distributions).

3.4 Conclusion

An oil spill sensitivity assessment was carried out on the Misratah shoreline. Identification and analysis of potential risks and damaged habitats on the coast were classified using the ESI approach. The study includes field mapping, GIS mapping and analysis of the vulnerability of the shoreline type in various geomorphic types. Data were collected during fieldwork, from unpublished study reports from oil companies working in Libya, and by using satellite images to derive information about the environmental settings of the study area, especially the intertidal sections and coastal communities. This study presents the first oil sensitivity map for the Misratah region and an initial assessment of around 14% of the Libyan coast.

The evaluation of oil spill risk was based on the identification of vulnerable coastal environments. This forms the most important part of a Misratah contingency plan, in order to respond quickly to an oil spill occurring in the area. The shoreline sensitivity index is the basis for prioritising oil spill containment and clean up.

In order to provide a tool serving as a quick reference for oil spill responders, the ESI ranks shoreline into eleven classes in relation to sensitivity, natural persistence of oil and ease of clean-up. The study found that the Eastern coast of Misratah is more sensitive to oil spill when compared to the Northern. On a scale from 1-9 in terms of sensitivity to oil spill, the low vegetated sections (ESI 9) are the most sensitive to oil spill. Exposed rocky shores and exposed man-made structures (ESI 1 and ESI 1 A) are the least sensitive to oil spills.

Chapter 4: Spatial and temporal variations of oil spill paths in the Libyan Western marine area: using GNOME simulations to determine coastal areas at risk

4.1 Introduction

Oil production is one of the main industries in Libya and requires massive infrastructure, including offshore drilling and exploration and oil export platforms located in coastal areas, with the biggest oil and gas storages on the western coast of Libya. (Brega Petroleum Marketing Company, 2013). Over 90% of crude oil loaded in the Mediterranean comes through North African ports in Libya, Algeria, Tunisia and Egypt (UNEP, 2008). 80% of Libyan crude oil is exported via oil tankers and pipelines in the Mediterranean Sea, in connection with pipeline terminals, refineries and offshore and coastal platforms along the Libyan coast. For example, the number of oil tankers directly crossing the Misratah marine area for oil loading in August 2013 was more than 14 ships, containing 11 million m^3 of oil (National Oil Corporation, 2013; Abomadina, 2002). This level of activity means that there is a threat to marine and coastal environments from spillages.

The potential for spills directly from the oil industry is augmented in urban areas by other sources associated with the industry and transportation. Unfortunately, the data necessary to monitor and evaluate the main tanker routes, oil storages and oil loading actions are very limited and not easily available. Oil spilt from tanker traffic, offshore oil industry and onshore sources are likely to increase due to the poor infrastructure on the Libyan coast (National Oil Corporation of Libya, 2016). There is, therefore, an urgent need to understand the likely destination of oil spills at different times and places along the coastline.

Although winds speed/direction, surface current, and wave energy are important factors, the type and amount of spilled oil, shoreline shape and coastal topography also influence movements of an oil slick (Olita et al., 2012). Few studies have been conducted using coastal oil spill simulations in Libya. This study is the first work investigating oil spill movement in the western coast of Libya, including the Misratah marine environment.

A more broad-scale study was carried out in the Southern Mediterranean Sea by the World Bank using the OILTRAJ model, developed by Det Norsek Veritas As (DNV). The model used by DNV in 2000 is one of several models used to simulate oil spills in the sea. Additionally, the MEDSLIK oil spill software is widely used and was applied by Aldo Drago (2008) around Malta, (The MEDSLIK Oil Spill Model for the Maltese Islands, 2015).

GNOME (General NOAA Operational Modelling Environment) computes the trajectory of oil spill for coastal and marine oil spill planning and remediation purposes. GNOME is an operational modelling environment that has been widely applied to simulate oil spill movement, e.g. the application was applied by Farzingohar et al. (2010) in the Persian Gulf around the Rajaee port to determine potential risk areas, and more recently in Gulf of Mexico (Mariano et al., 2011). GNOME has been used worldwide (Prabhu and Kankara, 2014; Romero et al., 2013; Deng et al., 2013; Cheng et al., 2011; Klemas, 2010; Vacchi et al 2013; Bejarano and Mearns, 2015; Farzingohar et al., 2011).

The advantages of GNOME are that it is freely available and supported by NOAA, a large agency, which supplies the winds and current data. While MEDSLIK and GNOME are freely available, some commercial alternatives exist. For example, the OILMAP software is used by the RPS ASA group. The software includes simple graphical procedures for entering both winds and hydrodynamic data and specifying a spill scenario (OILMAP, 2015).

In summary, the aim of this chapter is to create seasonal oil spill trajectory maps for the Misratah coast, including time-of-movement maps, i.e. the minimum time the oil would take to reach the coastal area. This kind of scenario building can help local authorities set agency plans for oil spill. Data on potential sources of spill were collected from different sources including local authorities, observation, and existing literature. The study area is reviewed in chapters one, two and three, and represents a 248 km section of sandy and cliff coastline with wide and narrow shores, and 50% of the coast covered with wetlands (Alkoja, 2002).

4.1.1 History of oil spill accidents

Although Libya is a part of United Nations Environment and the Mediterranean Sea protocols and plans, information on oil spills is limited and unpublished. More detailed information on possible pollution sources was collected through the fieldwork and through Libyan authorities' reports (Environmental General Authority, 2013), described in earlier chapters, and according to recent studies and environmental technical reports from the Environmental General Authority and the Department of Health, Safety & Environment in the National Oil Corporation. The Misratah coast is considered at a high oil spill risk due to increased offshore oil industry and maritime activity, including oil tanker traffic in the coastal area, oil loading/uploading in seaports and coastal development (Figure 25). The most immediate risk comes from accidents occurring during loading/unloading oil in the Misratah harbour (Figure 24).

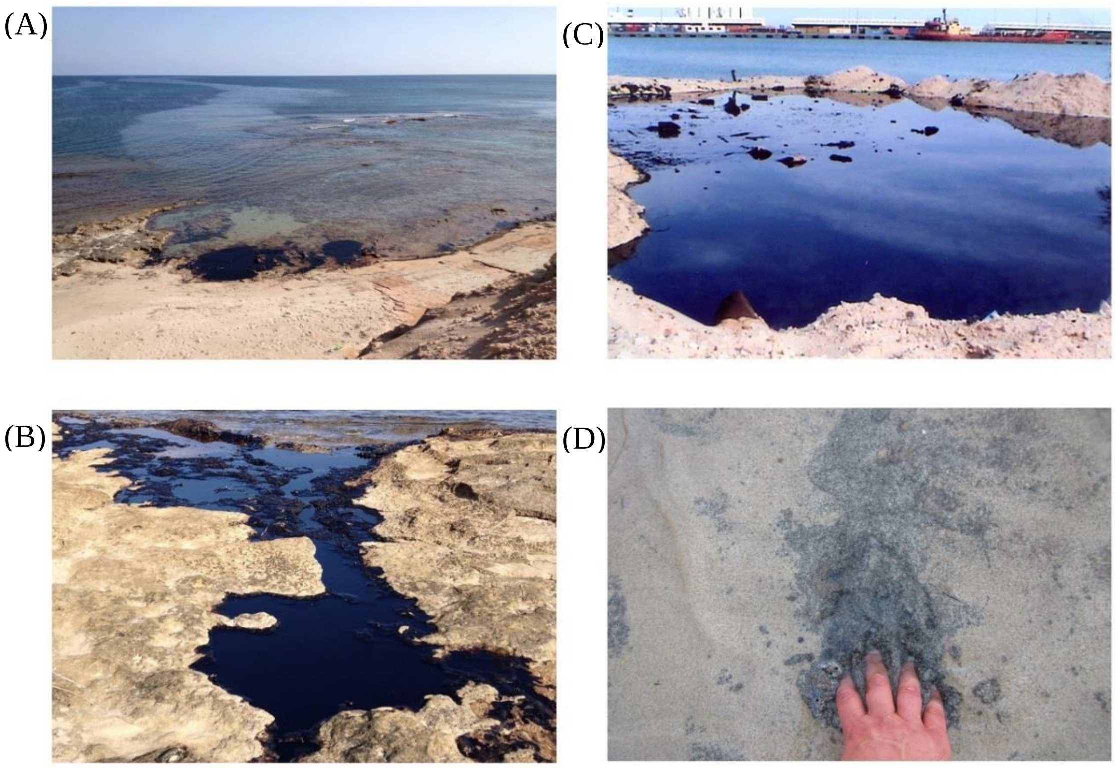


Figure 23 Cases of coastal oil spill in 2013 and 2014. (A) oil tracks at Misratah coast after oil spill accident near the shoreline, (B) the spreading of oil slick on the rocky shore after being pushed by wave and wind energy, (C) accumulation of oil in the Misratah harbour which is coming from the leaking of oil pipeline to the shore, (D) oiled sandy beach in Misratah coast in 2015, Libya.

4.1.2 Frequency and probability of oil spill occurrence

Providing occurrence data and cumulative frequency distributions for coastal and offshore oil spill is useful for developing potential oil risk area maps and assessing oil spill in the coastal area. The oil spill probability from the socio-economic activity in the Misratah coast is high, because of poor infrastructure and maintenance of the ports and oil industry facilities. This study investigates major and minor oil spill sources on the Western Libyan coast.

The minor spill sources were determined from actual spill releases because of the frequency of occurrence from different elements in the coastal area, such as the iron industry complex, fishing/ports activity and tanker traffic. However, the most common oil events in Misratah were from operational accidents during oil loading on the platform or oil tanker accidents.

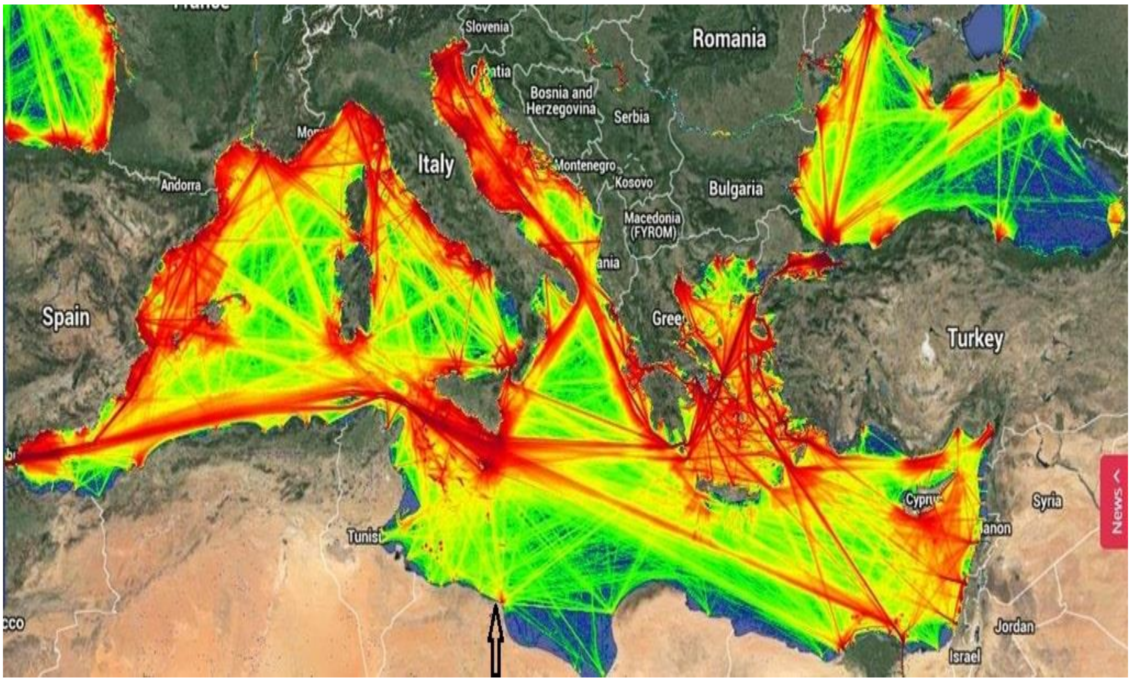


Figure 24 The central Mediterranean Sea and Misratah coast presented on high oil tanker route, Red colour indicates high oil tanker transportation near Misratah region (Libya Shipping Agency, 2016).

4.1.2.1 Minor spill sources

Oil pollution sites for simulations were selected to represent coastal activity and offshore oil exploration, as this work investigates the potential damage and risk to coasts from surface spill due to 17 oil spill sources (Figure 26). According to fieldwork data and local government reports gathered from the Misratah authorities, there are 33 car wash stations in the Misratah city releasing expired oil into the public sewage system, which flows out to the coast without recycling. The expected number of the oil spill from the urban area – non-stop spillage - was calculated according to the local environmental reports from the Environmental General Authority and fieldwork data. The flow through each pipeline is 267 L day^{-1}. Other oil spill resources come from fishing ports; for example, the Zurek port is releasing 100 L month^{-1}, the Gaser-ahmed port 500 L month^{-1}, and the Aljazeera port 69 month^{-1}. The rest of the oil spill comes from the iron factory (Coastal Environmental Protection Department, 2007).

4.1.2.2 Major spill sources

The major oil releases are based on oil production on the Western coast of Libya. Oil refining, oil export ports, offshore oil platforms and oil loading/unloading are distributed along the western coast of Libya. The Alsalam and Alborry offshore oilfields are located on the west side of Libya, near to the Tunisian border, oil refinery and oil export ports are located 100 km far from the west of Tripoli on the coastal area, and the Koums oil platform is located in the coastal area 100 km far from the west of Misratah. However, the four oil spill resources on the Eastern Libyan coast were excluded as prevailing winds and current make them unlikely to affect the study area. Proposed oil spill sources were simulated in the GNOME software because the impact of oil spill in a different area of the Libyan marine area might also affect the Misratah coast (Figure 26).

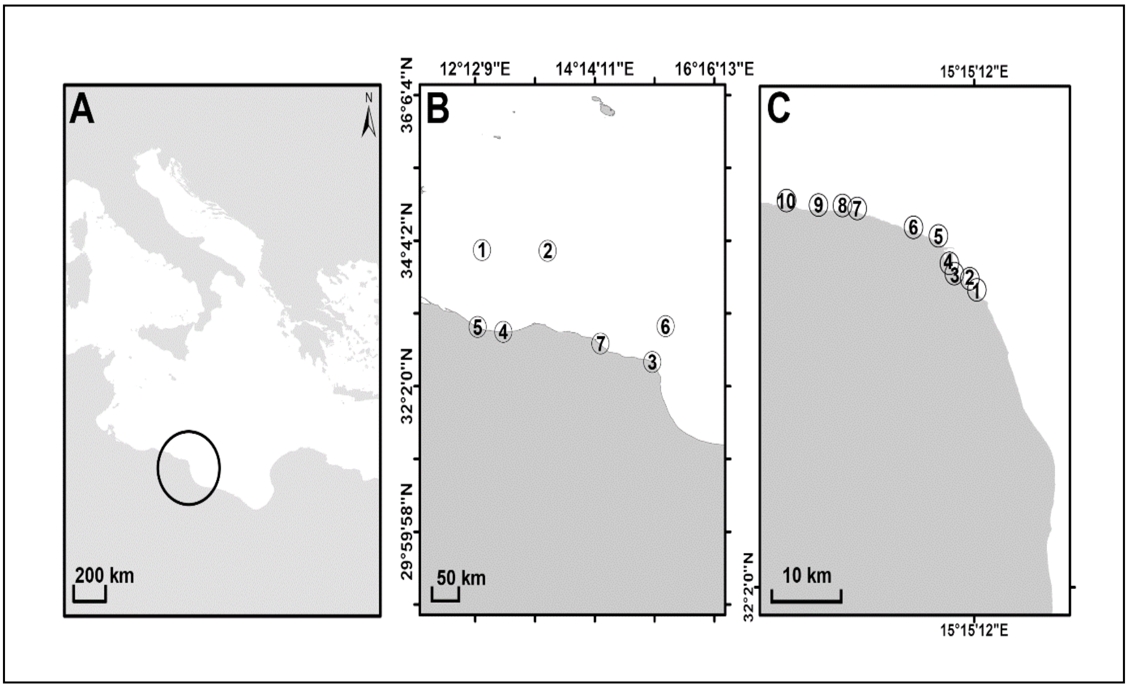


Figure 25 Oil spill locations along the (A) Libyan coastline, (B) major oil release and (C) minor oil release locations. Site names and release rates modelled are given in table 5.

4.2 Methods and materials

4.2.1 GNOME model

The GNOME software was originally developed to be applied to make forecasts for USA coastal sites, but recently the software has been extended to work in different regions supported by an environmental data access server (Beegle-Krause, 2003), enabling the study of past and current oil spills (Simecek-Beatty and Lehr 2007). The GNOME software can provide information about the likelihood that a spill will contact the coastline.

For Misratah, a relatively high risk of an oil spill at the coast is expected due to industrial activities and the discharge into the sea through the sewage system (Abuissa et al., 2005). Spill simulations were performed with environmental data from two periods: 15 January to 16 February 2015 to represent the winter season and from 15 July to 15 August 2015 to represent the summer conditions. The coastline map was generated in the NOAA software and modified to the Libyan coast and marine environment based in the processes in Figure 27.

The GNOME online oceanography data server (GOODS) provides access to a weather database; surface current data in the summer and the winter season were extracted from GOODS for simulations (see below). In addition, GOODS includes a map generator tool that can be used to make a GNOME base map (Samuels et al., 2013). Winds data available from GOODS are from the National Data Buoy Centre (NDBC), where the user can choose the relevant station. Unfortunately the nearest NDBC meteorology station to Libya is in France. Therefore the winds data were derived from the Climatology of Global Ocean Winds (COGOW) online winds resources.

Oil is modelled in GNOME as a series of several hundred ‘splots’, essentially Lagrangian drifting ‘parcels’ of oil. Smaller numbers of splots make the model faster, but using too few means that the results are not statistically representative. 1000 splots is a typical number for simulations. GNOME simulates the path of each splot of oil on the surface, subject to currents, winds and diffusion. All three processes are interpolated and applied at any point in the model to generate a displacement distance and direction for oil. Wind is applied using a scaling to account for the drag on floating oil. Diffusion is a stochastic process linked to small scale hydrodynamics and waves. GNOME models this as a random walk based on a diffusion coefficient of 100,000 cm^2s^{-1}. As is the case for many of the GNOME parameters, this is a heuristic, based on reasonable expectations and experience with applying the model.

Oil is subject to weathering in GNOME. This is modelled as a loss of different light, medium and heavy fractions dependent on their volatility. Under this simplification, each oil fraction has a different half-life. Lighter components typically have a half-life of less than a day. The heavy component of diesel will be reduced by about 88% in 30 days. In contrast the heavy component of crude oil has a half-life of 10^9 hours, so will be little degraded in 30 days (NOAA 2012). If all the oil evaporates from a splot, simulations for that patch stop and the oil is considered fully dispersed and no longer a visible pollutant.

Maps produced by GNOME software were exported to ArcMap (ArcGIS 10.2 ESRI) and saved as layers (NOAA, 2002). To project oil spill maps by the software, four elements were developed:

- Location file: the Libyan coast is not covered by NOAA, so a new location file was generated for the coast.
- Winds speed and direction was created from online available winds data and the average of winds speed and direction in both seasons.
- Current data: the GOODS server offers current data for the Mediterranean Sea from global and regional ocean current models (NOAA, 2002).
- The oil release rate and duration for a worst-case scenario.

The model simulations provide estimated oil trajectories on the sea surface, based on the actions of winds, current, tides, and diffusion (NOAA, 2002). Output from GNOME can be exported as QuickTime movies or Geographic Information System (GIS)-compatible Split files that can be loaded and compiled with ArcGIS.

Oil dispersion was simulated using GNOME to produce hazard maps for the study area. Oil spill trajectories were run for the Misratah coast and marine environment at 10 locations in the coastal area that were considered minor oil sources and one major potential source in the offshore area. The model was run for 30 days, taking into consideration the absence of contingency plans to oil spill accidents and to determine the final deposition area in the study area (Deng et al., 2013). In order to include the worst-case scenario for the spread of oil and related environmental impacts, the study area extended as far as 300 km away from the spill spot in the Libyan coast to include the marine area around the major offshore oil platforms of Alsalam and Alborry (Bouri).

Additionally, a hypothetical offshore oil spill from a platform on the Koums coast (100 km faraway from Misratah city), and other sources in the west end of the Libyan coast were examined in GNOME software to investigate if remote spills can reach the Misratah coast according to winds and current in either season.

4.2.1.1 Uncertainty

Climatological average winds and simulated can often only approximate the factors affecting the movement of oil. Even if data were available from the point of an oil spill, this would only be an estimate of the conditions patches of oil experience as a slick spreads. This uncertainty of ocean current and winds speed/direction may also be influenced by the complicity of shoreline and bottom bathymetry. Therefore, the uncertainty of the Misrata oil spill model parameters was considered to be 10%, as recommended in the guidelines of the GNOME software. This is based on experience of the accuracy of predictions and leads to a ‘minimum regret’ solution that is intended to identify all areas that may potentially receive oil. Simulations show the uncertainty in the maps using a red colour, which provides an estimation of where oil could possibly spread (Sebastião and Soares, 2007).

The characteristics of spilt oil are also uncertain. Some spills may be crude oil, but other processing levels of oil may be being transported and small scale pollution may also be varied. As minor oil spills may be released semi-continuously, a relatively long simulation time may be appropriate. Following the minimum regret approach, oil was simulated using the parameters for crude oil with a 30 day simulation period. This was thought to give a good approximation of where diverse types of oil may end up, while minimizing the risk that particularly vulnerable areas would not be identified.

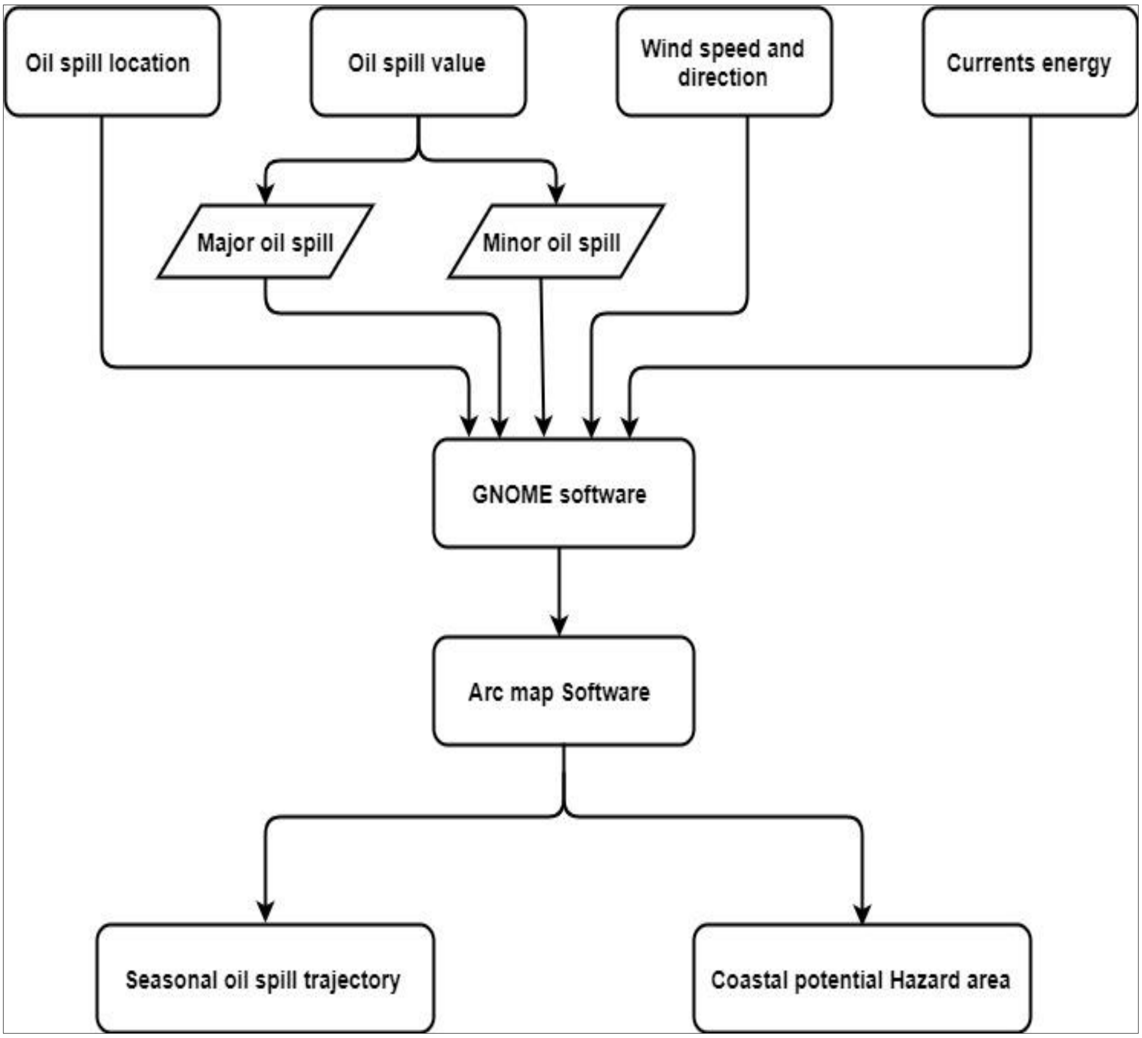


Figure 26 Flowchart for the numerical simulation of oil slick movement. The model ran for 30 days. Each of the represented parameters is explained in detail in the text. The amount of minor and major oil release data used for oil spread modelling is presented in Table 5. Potential oil spill locations, offshore and onshore, are along the study area. Files required to run GNOME in its standard configuration were generated from NOAA hosted sources, with the exception of wind speeds and directions in summer and winter from the Climatology of Global Ocean Winds (COGOW, 2006). The surface current data were obtained from NCOM (Navy Coastal Ocean Model), made available by NOAA.

4.2.1.2 Ocean current

For oil spill simulations in GNOME, winds and ocean current are needed (NOAA, 2002). Current is the key factor for redistributing spilled oil (Deng et al., 2013; Carracedo et al., 2006). The surface current data were obtained from NCOM (Navy Coastal Ocean Model) (Beegle-Krause, 2003). Spill simulations ran from January 15 to February 15 in 2015 and from July 15 to August 15 in 2015.

The required currents are generated by the global HYbrid Coordinate Ocean Model (HYCOM) site is based the National Ocean Partnership Program (NOPP), as part of the U. S. Global Ocean Data Assimilation Experiment (GODAE) (Hycom, 2017). The system provides a real-time current and tide information in 3-day, daily forecast at approximately 9-km (1/12-degree) resolution (Deng et al., 2013). The ocean model vertical coordinate is isopycnal (layers of constant density) in the open stratified ocean; (1) z-level and (2) terrain-following in shallow coastal regions, and z-level in the surface mixed layer.
The domain of the circulation model was set from longitude 17.284E - 11.604W and latitude 30.553 S - 34.796N, covering Misratah sea and part of the Western coast of Libya, with 1-meter depth layers (Hycom, 2017).

The Misratah offshore currents coast are weak, reflecting the low speeds in the Mediterranean; the coastal current along the Libyan coast is even weaker (Robinson and Leslie, 2001). Therefore, the current has a larger influence on oil movement at sea as compared to the coastal area, which is characterized by maximum speed of 15 cm s^{-1} (Poulain et al., 2012). Figure 28 shows that the Mediterranean current in winter season flows generally in a westerly direction, from near the southwest of Malta, and from the north to the south of the Gulf of Sidra. In the summer season, however, the current direction generally continues north-westerly direction toward the Gulf of Sidra but near shore eddies restrict the movement toward the Libyan coast (Gerin et al., 2009).

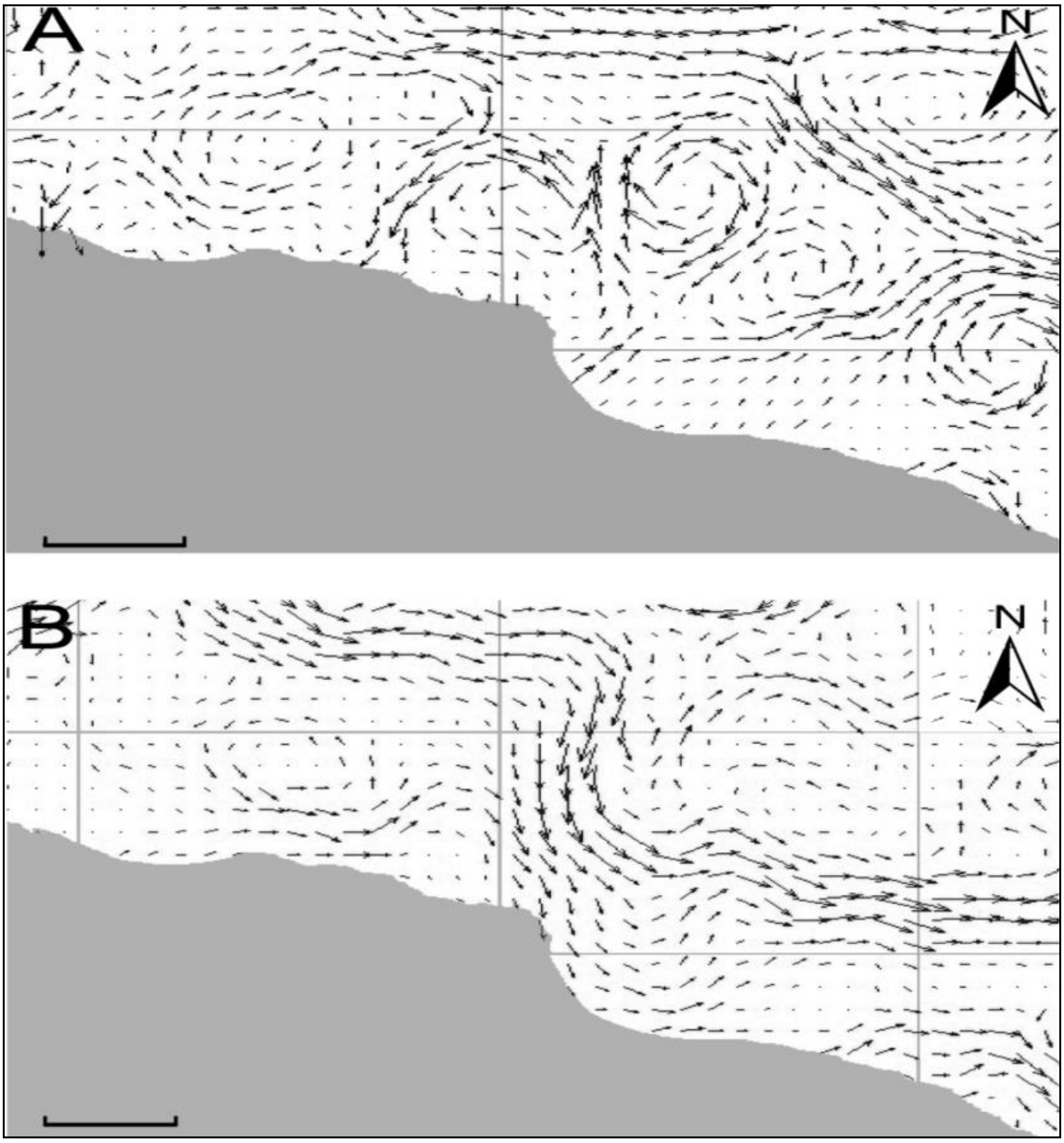


Figure 27 Mediterranean current surface direction in (A) July (B) January 2015. Scale bar 50 km (NOAA- STAR, 2015).

Table 5 Major and minor oil release location data used for oil spread modelling

Model	Site	Location	latitude and longitude	Release rate L/d
Major oil spillage				
1	Alsalam oil platform	Offshore*87 km	33°49'56.93"N 11°56'30.30"E	4,769,619
2	Alborry oil platform	Offshore *125 km	33°55'59.14"N 12°54'14.52"E	5,928,636
3	Misratah oil loading platform	On Coast	32°22'17.56"N 15°12'47.78"E	31,797,459
4	Zawiya oil export port	On Coast	32°47'35.46"N 12°40'49.33"E	19,078,475
5	Mellitah Refinery	On Coast	32°51'46.79"N 12°14'31.36"E	4,928,606
6	Misratah oil field	Offshore*96 km	33° 8'43.64"N 15°23'6.94"E	2,543,797
7	Koums oil loading platform	On coast	32°37'47.25"N 14°20'1.20"E	7,949,365
Minor oil spillage				
1	Gaser Ahmed port	On Coast	32°20'0.44"N 15°15'1.72"E	17
2	Gaser Ahmed 1	On Coast	32°20'13.52"N 15°14'28.15"E	10
3	Gaser Ahmed 2	On Coast	32°20'40.23"N 15°13'53.11"E	10
4	Gaser Ahmed 3	On Coast	32°20'43.67"N 15°13'48.86"E	10
5	Gaser Ahmed 4	On Coast	32°20'56.31"N 15°13'37.46"E	10
6	Sour Saud (sewage pipe)	On Coast	32°23'26.57"N 15°10'49.50"E	267
7	Jannat (sewage pipe)	On Coast	32°24'44.79"N 15° 4'56.84"E	267
8	Aljazeera (sewage pipe)	On Coast	32°24'45.02"N 15° 2'45.83"E	267
9	Aljazeera port	On Coast	32°25'8.00"N 15° 0'18.11"E	2
10	Zurek port	On Coast	32°26'20.62"N 14°54'6.63"E	7

Summer conditions: Sea 28 °C, air 32 °C, winds speed 10 knots, winds direction N to NE, 15 July to 15August 2015. **Winter conditions**: Sea 17 °C, air 32 °C, winds speed 20 knots, winds direction E to EN, 15 January to 15 February 2015. Major oil release rate in (1, 2 and 6 sites) based on oil production, (3, 4, 5 and 7 sites) based on oil loading/uploading. Minor oil release rate based on (1, 9 and 10 sites) in Misratah ports, (6, 7 and 8 sites) based on oil spill come through sewage pipes, (2, 3 and 4) based on dally release come from iron and steel factory.

4.2.1.3 Winds

Wind speed and direction is considered as a major influence on oil spill movement, controlling slick behaviour and distribution (Kim et al, 2014).The Northern winds in the study area induce the movement of the oil slick directly to the Misratah coast in both seasons. The winds data for the stochastic models has been sourced from the climatology of global ocean winds and covers the vicinity (Figure 29) of the Misratah coastal area for a period of 10 years from 1999 to 2001 (COGOW, 2016). For the purpose of these models, data from the middle of January to the middle of February (appendix 4) will be used to represent typical case winter wind conditions (equivalent to 10 m weather station records) and data from the middle of July to the middle of August (appendix 4) were used to represent typical case summer winds conditions.

Figure 29 shows that winds tended to be from the north all year, tending to northwest in January and February and Northeast from March to October, except for the months of November and December, where the winds blow mainly from the west. During the summer time winds are light, blowing toward the southeast with speeds less than 11 knots. In wintertime the winds come from east and northeast with speeds of 17 knots.

However, while in August the winds come from the north-northeast with speed of 9 to 15 knots. In general, the highest daily average winds speeds occurred during the winter months and were up to 18 knots. In contrast, from June to August the winds speeds were around 6 knots.

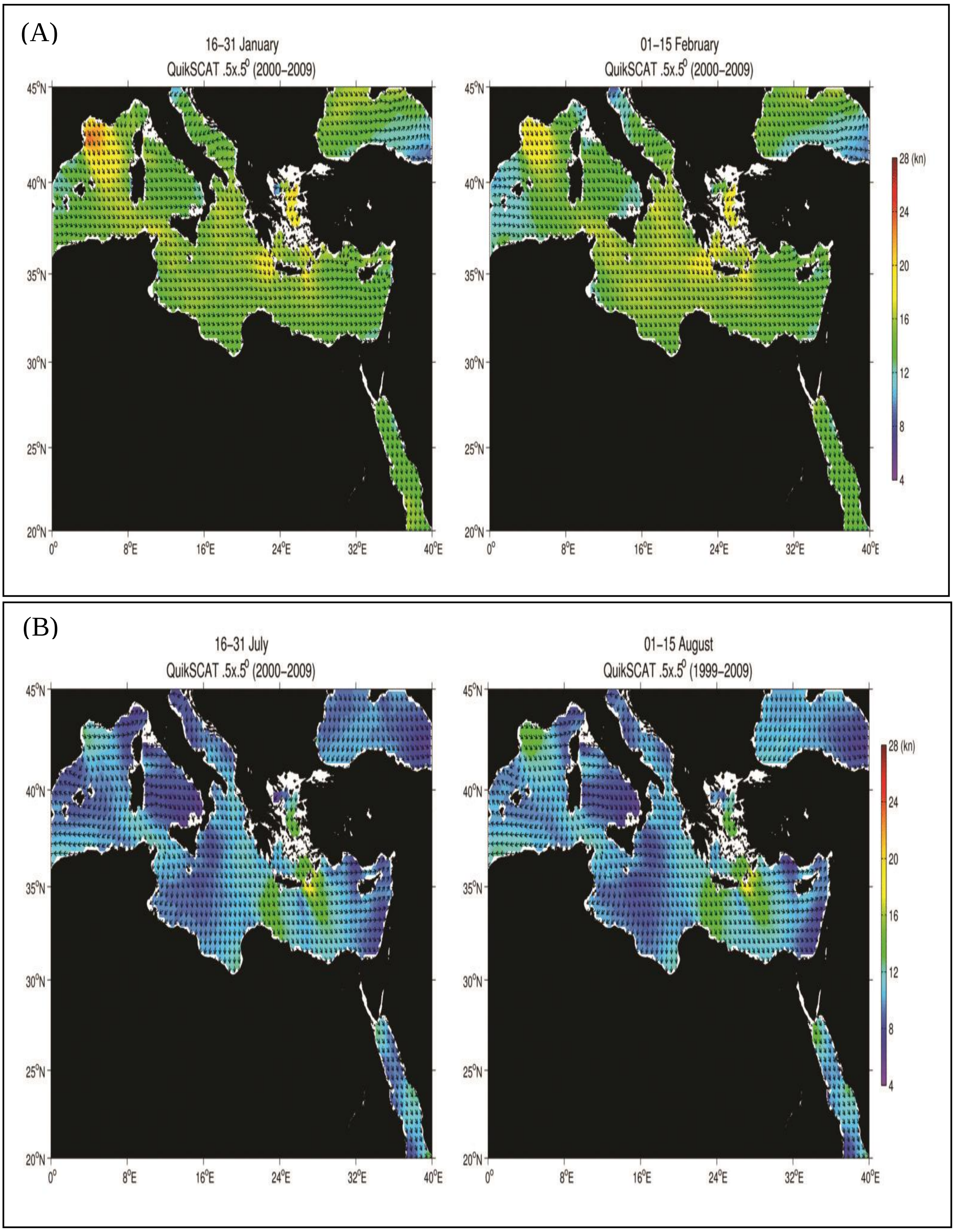


Figure 28 (A) Monthly distribution of winds speed and direction in February in the Misratah area, (B) monthly distribution of winds speed and direction in August in the Misratah area (Wind Finder, 2015).

4.3 Results and discussion

4.3.1 Modelling oil spill pollution

Oil spill trajectories were simulated to identify the potential locations of beached oil to reduce and prevent their impacts. Oil spill simulations were carried out considering the seasonal variability of winds, wave and surface water current. Misratah winds events were characterized by average speed values of approximately 6 knots and by maximum values of more than 17 knots, for the summer and the winter. The oil movement scenarios were generated for February and August to represent the summer and winter seasons.

4.3.1.1 Oil spill trajectory on the Misratah coast

Oil trajectory analyses have been used to investigate the risk from offshore and coastal oil spills along the Western coast of Libya. Scenario-A, a major spill at the Misratah loading platform in winter months, was run with West and West-Northwest winds directions with winds speed between 12 and 16 knots. The simulation results show that the spill could reach the wetland coast only under high-speed westerly winds; the prevailing winds direction moves spill off the Misratah coast, approximately 80 km to the East. The oil spill affected the South side of the Gulf of Sidra and that the spill reached the coast (Figure. 30B). The summer oil simulation was run at 7 knots winds speed and a northerly winds direction, reaching the Misratah coast between North-Northeast to North-Northwest, then in the next 3 days winds speed was increased to 9 knots. The oil trajectory slowly moved in parallel to the wetland coast to the Southeast (Figure 30A). After 15 days, the winds came from the North and then the oil slick was deposited on the wetland coast. Furthermore, the oil might affect the coastal segment around oil spill sources. The major oil spill simulations compared winter and summer using the same dataset (winds, current and hypothetical oil value). The results show that the Misratah coastline is more vulnerable to oil spill movement in the summer than in the winter.

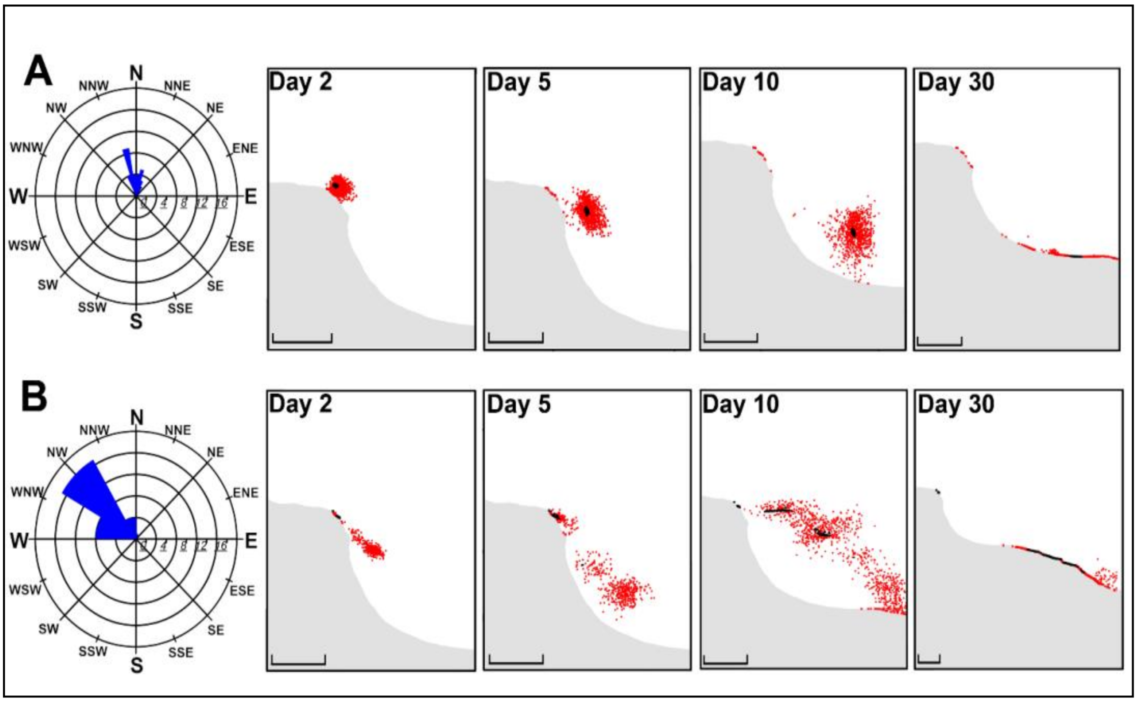


Figure 29 GNOME outputs a hypothetical oil spill on the Misratah coast, (A) during the summer and (B) the winter in 2015. Major oil spill, model number (3) as shown in (Table 5), scale bar represents 50 km and winds speeds are in knots. Black points present "best guess", red point represent the uncertainty due to wind and current variability.

In contrast to a major spill in Misratah, Figure 31 shows the predictions for small oil spill locations are distributed on the north coast. Ten minor oil spill sources on the Misratah coast were investigated in both the dry and wet seasons, where the winds comes from the North and North East, computed from 15 July to 16 August (Figure 31A). This indicates that winds during the first half of the oil simulation were more from the North and North-Northwest, while from 15 January to 16 February, winds were more Westerly. Comparing between the oil slick in 2 days in both seasons, oil spill distributes on the coastal area due to the North winds direction (Figure 31A, B). In the same period, however, the slick moves to the Southeast, according to general winds direction at this area. After 30 days of GNOME simulation, most of the east coast of wetland was affected by oil, as was the Gaser-ahmed area on the north coast. The important point about oil simulation in 30 days (Figure 31 A, B) is that the pollutant area in the summer season is much smaller than is the case in the winter simulation. Furthermore, the oil pollution is almost totally confined within the onshore area around the oil spill origins.

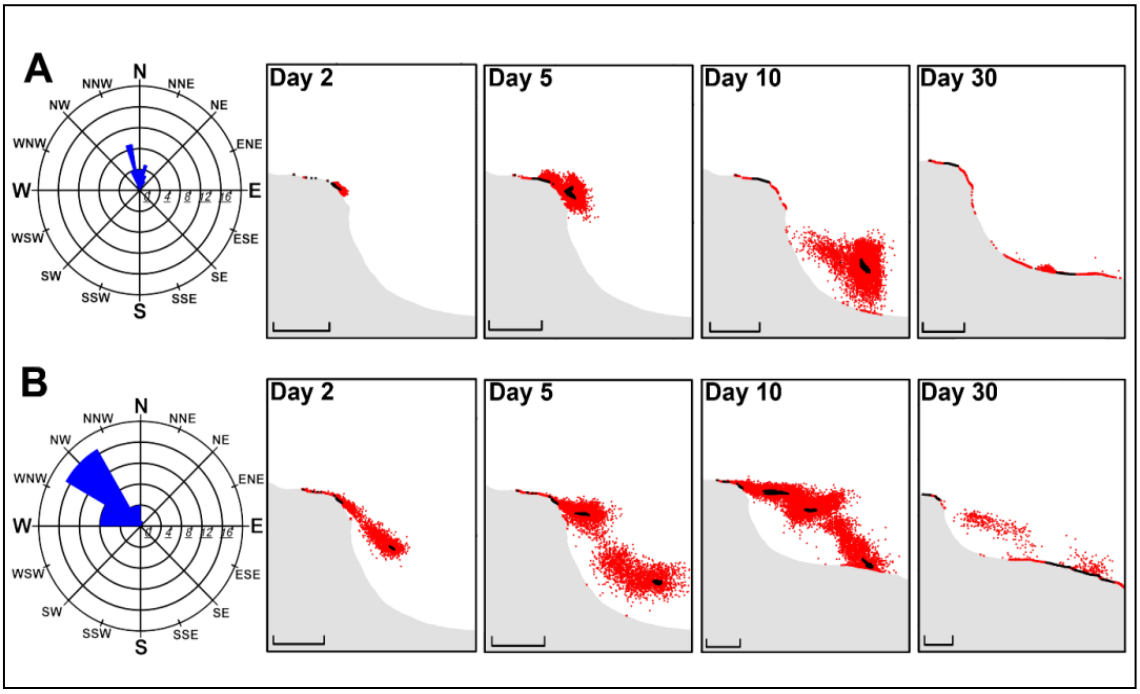


Figure 30 GNOME outputs for oil spill at Misratah coast, (A) during the summer and (B) the winter in 2015. Minor oil model numbers (1 to10) as shown in (table 5), scale bar represents 50 km and winds speeds are in knots. Black points present "best guess", red points present uncertainty.

For a simulated spill in the Misratah offshore oil field (96 km from land), the winds blew from the north and northeast in the summer and from the west and northwest in the winter, with the higher average winds speed of 8 knots in summer and 17 knots in winter. Because of the local environment factors in the Gulf of Sidra, oil could travel all the way to the Misratah shoreline. After 30 days of simulation, the oil slick moved 300 km from its origin. During the simulation period most of the likely oil patch locations were confined to the sea in front of the study area and towards the Gulf of Sidra to the East. Figure 32 A and B shows that in both seasons, a similar shape of slick spreading in the Libyan marine environment, due to winds and current conditions. The results of the simulation show that the oil slicks move away from coast in the two scenarios. However, for the 30-day simulation in the summer season, there is a probability that the slick might spread on the coastline under the prevailing winds direction.

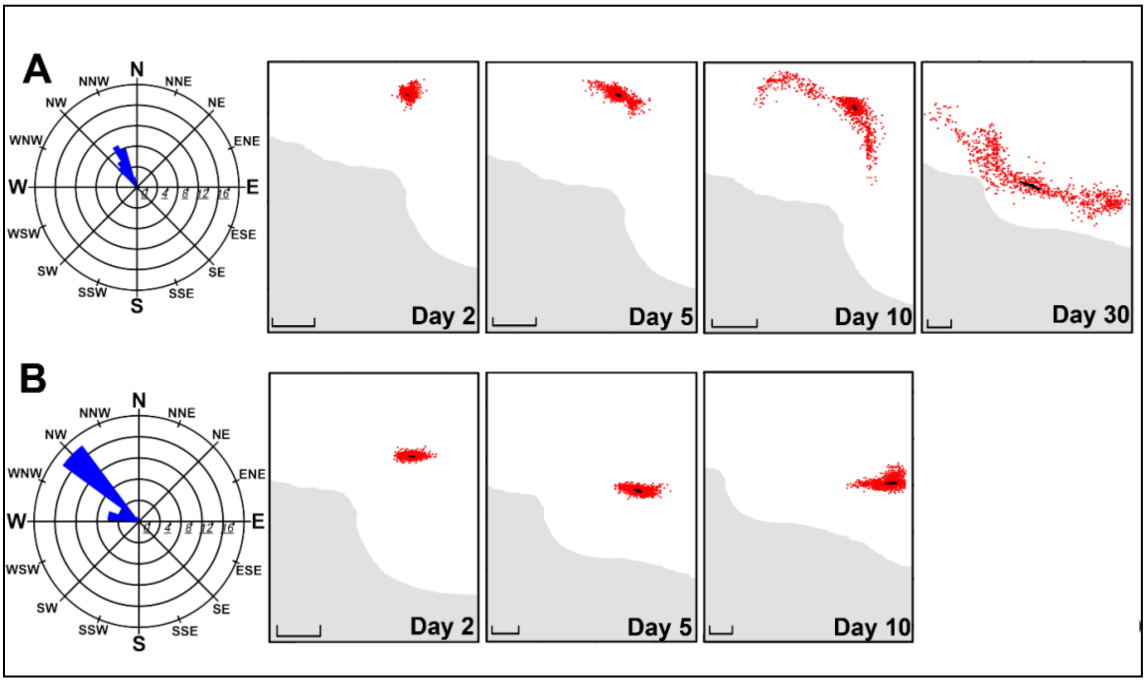


Figure 31 GNOME outputs for the hypothetical oil spill at Misratah offshore water (A) during the summer and (B) the winter in 2015. Major oil spill, model number (6) as shown in (table 5), scale bar represents 50 km and winds speeds are in knots. At day 30 of the winter scenario oil spill the slick is carried out of Misratah due environmental and oceanographic factors. Black points present "best guess", red points present uncertainty.

The oil slick could potentially 5 days to reach and cover the saltmarsh in the Eastern Misratah coast. However, in the wintertime, the slick is carried out of Misratah over 30 days due to the prevailing environmental and oceanographic factors.

4.3.1.2 Oil spill trajectory on the Koums coast

Oil storage facilities on the Mediterranean coast, located 100 km West of Misratah, are an important oil terminal for Libya and a possible source of pollution. The hypothetical oil spill simulation of such an event illustrates that the oil spill moves to the East, toward the Misratah marine environment. Figure 33A and B show the oil slick moving to the East near the coast with a spread along the Koums and Zliten coasts. Furthermore, the oil slick reached the Misratah coast in 10 days, and subsequently, the south coast of the Gulf of Sidra might be affected by oil pollution within 30 days in the winter.

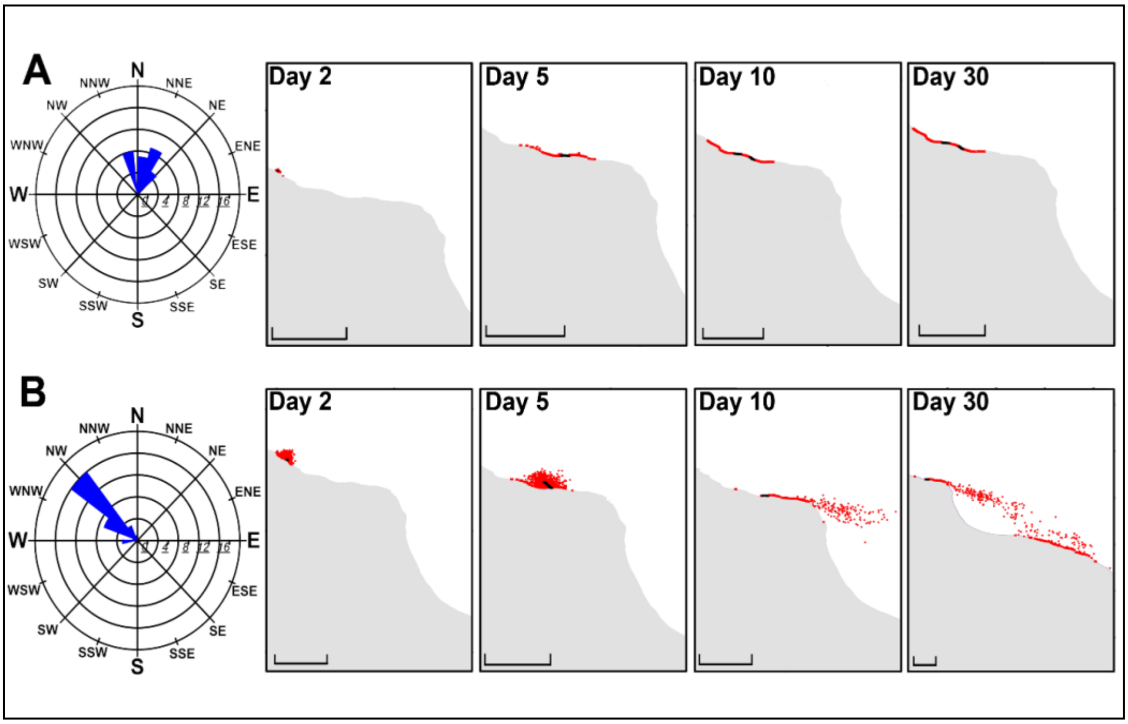


Figure 32 GNOME outputs for the hypothetical oil spill at Koums coast, (A) during the summer and (B) the winter in 2015.Major oil spill, model number (7) as shown in (table 5). The scale bar represents 50 km and winds speeds are in knots. Black points present "best guess", red points indicate uncertainty.

4.3.1.3 Oil spill trajectory on the Zwara coast

The offshore and onshore hypothetical oil spill originated at Mellitah and Zawiya on the Western Libyan coast. The oil simulation ran for 30 days in the summer and winter; the model ran from 15 January to 16 February for the Zwara simulation stage. The winds during the winter period are mainly north-westerly (Figure 34). The oil generally moved in the same direction as the winds, moreover the modelling results show the oil slick spreading to the Tripoli coast after 5 days. After 30 days, an oil slick in the winter time may affect the Misratah coast. This oil spill source would probably not pollute the nearshore waters of Gulf of Sidra, as (figure 34) illustrates, the pollutants remain in the coastal area after 30 days, generally confined to the Tripoli and Zliten coasts west of the study area.

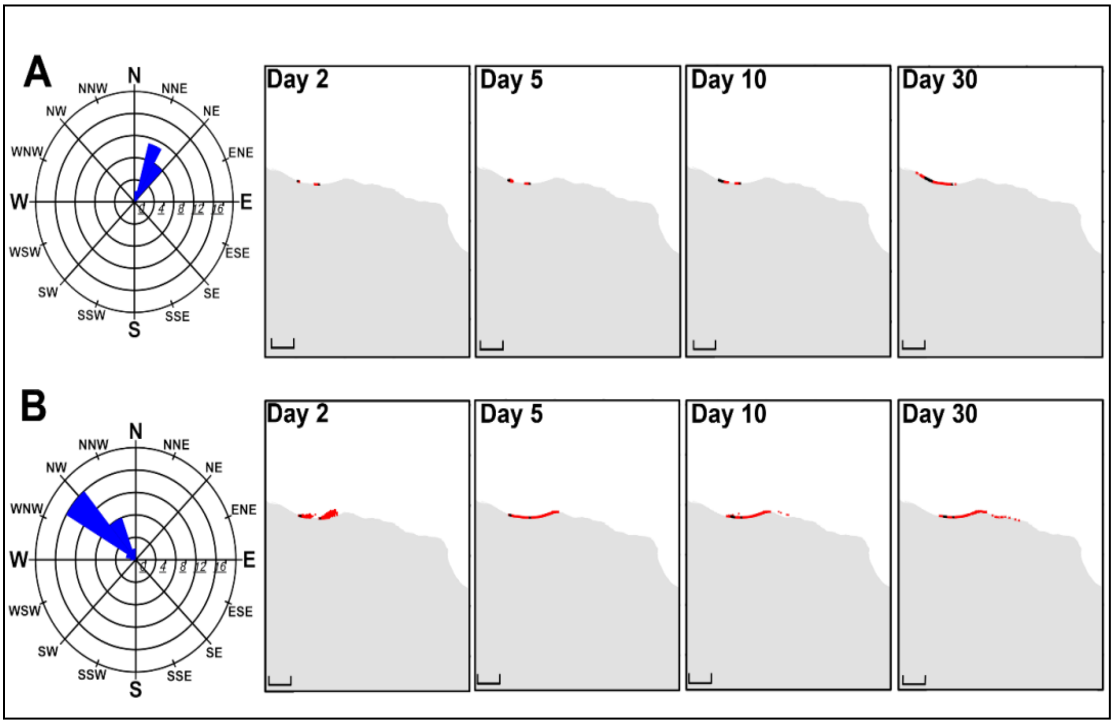


Figure 33 GNOME outputs for the hypothetical oil spill at Tripoli coast, (A) during the summer and (B) the winter in 2015. Major oil spill, model number (3 and 4) as shown in (table 5), scale bar represents 50 km and winds speeds are in knots. Black points present "best guess", red points represent uncertainty.

To understand if a hypothetical oil spill from 300 km west of Misratah may reach the study area, the oil spill trajectory in offshore water was run for two sources: (1) the Alsalam and (2) Alborry oil platforms. In the summer simulation, the spill generally moved to the southeast, approximately towards the west Libyan coast. After 10 days, the slick spread on the Tripoli coast due to changeable winds direction. In addition, in a scenario where the winds are from the North and the Northeast for the 30 days of simulation, the result is an elongated pollution region, threatening an extensive coastal region on the West coast of Libya, covering more than 200 km by the end of the 30 day simulation (Figure 35A). However, the effect of winter winds on oil spill direction was that after 2 days the slick moved to the east toward the Misratah coastal marine area and after 10 days, the oil track changed towards the Koums coast. Figure 35 B shows that the slick might deposit on the north cost of Misratah.

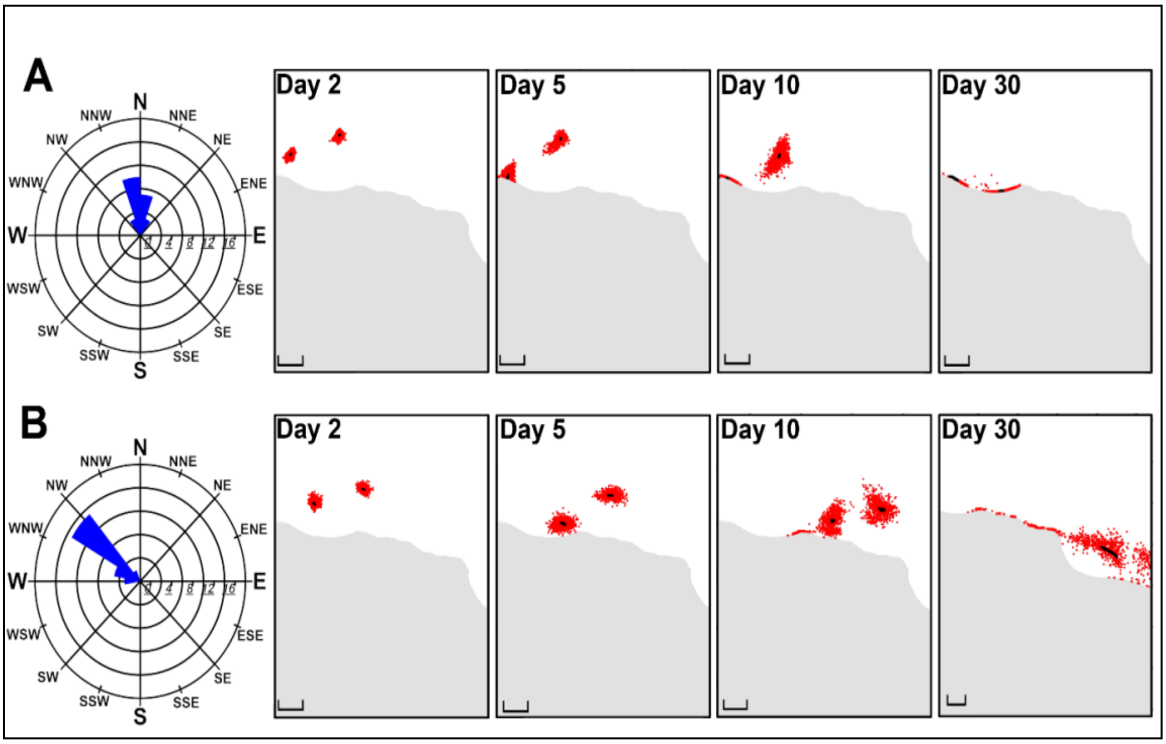


Figure 34 GNOME outputs for the hypothetical oil spill at Tripoli offshore water coast (A) during the summer and (B) the winter in 2015. Major oil spill, model numbers (1 and 2) as shown in (table 5), scale bar represents 50 km and winds speeds are in knots. Black points present "best guess" oil locations, red points indicate uncertainty.

As it has been noted previously, the winds in the region come from different directions with variable speeds, but the prevailing winds vary according to the season, with the winds in the winter coming from the North and East and from the North and West in the summer. Simulations were run to model a series of oil spill accidents in the Western Mediterranean Sea, with a total of 41 oil spill simulations, computed for 6 different locations in the Misratah coast and the West coast of Libya. Simulation output suggests that oil slicks on the Misratah coast will reach the Northern and the Eastern coast of Misratah in two to ten days in summer conditions. Finally, oil slick trajectories are controlled by general winds and current eddies and therefore, oil slicks coming from oil spill in the Koums or Zwara areas might reach the coast in 30 days in the winter season. Based on these results, the general pattern across the simulations is the progressive movement of oil towards the South and South-East in both summer and winter conditions.

4.3.2 Shoreline hazard mapping

This study presents scenarios for several theoretical oil spills occurring in western Libyan waters, where the majority of the Libyan oil and gas industry is located. The following petroleum areas were considered in the study: Misratah, Koums, and Tripoli. The probabilistic oil spill simulations were carried out for 30 days in the GNOME (General NOAA Operational Modelling Environment) model, fed by synoptic wind data and current data. Simulations indicate the areas at potential risk areas from oil spills. The shoreline hazard index can help the operator to estimate the location of oil spill and to quantify it. Moreover, a planner can predict where a hazard may occur and how much time an oil slick may take to reach the coast (Bejarano and Mearns, 2015). Therefore, this information allows decision makers to develop a plan for response options that minimizes damages to coastal habitats (Assilzadeh and Gao, 2008).

Figure 36 shows the probabilistic oil hazard areas along the western coast of Libya. The summer hazard indexes are shown in boxes (A) of all figures, whereas the winter probabilistic hazard oil maps are shown in the boxes (B). Each map in two figures displays shoreline hazard probability contours which were computed from 17 potential oil spill resources. The oil hazard map (figure 36) demarcates the coastal areas under the risk of oil pollution where socio-economic activity may be affected, including coastal habitats and species.

The monthly maps of the hazard index distribution for the Misratah and surrounding shorelines are show a quite homogeneous distribution, with the north coast of Misrata most exposed to oil spills in the summer and the winter.. Conversely, the eastern coast appears less vulnerable to such risks.

Oil spill modelling results (Figure. 36 A, B) show a potential oil slick deposition area resulting from oil spillage in the Koums oil platform situated 100 km far on the west side of the study area; the north coast of Misratah might be affected in both seasons. In the summer, potential oil spills could spread over about 50 km along the area between Koums and Zliten, reaching approximately 50 km from the Dafnia to Gaser-ahmed area. However, during the winter periods, the shoreline area between Buerat and Sirte may be reached by the oil slick, whereas in the area between Gaser-ahmed and Buerat, oil is rare. Comparisons of hazard shoreline area which are affected by oil slick occurred from offshore of industry 96 km off Misratah coast. The probabilities of the appearance of the slick along the 50km of the north coast area and 20 km at the Gaser-ahmed segment of the eastern coast are high (Figure. 36 C). However, the appearance probability of oil slick on the eastern coast obviously decreases in the summer time (Figure. 36 D). Oil slicks in either season may reach the Sirte shoreline area on the east side of the study area.

According to hypothetical spills from the four potential spill sites (two offshore and two coastal area), the likelihood of pollution effects on different target zones in each season, summer and winter, could be illustrated. The impact probability of oil slick occurs in Zwara area 320km west Misratah to reach the study area coast in the summer time is low, oil appears within the area between Tripoli and Zuwarah in 120 km (Figure 36 G, H, I). However, oil could reach the north coast of Misratah in the winter season (Figure 36 J).

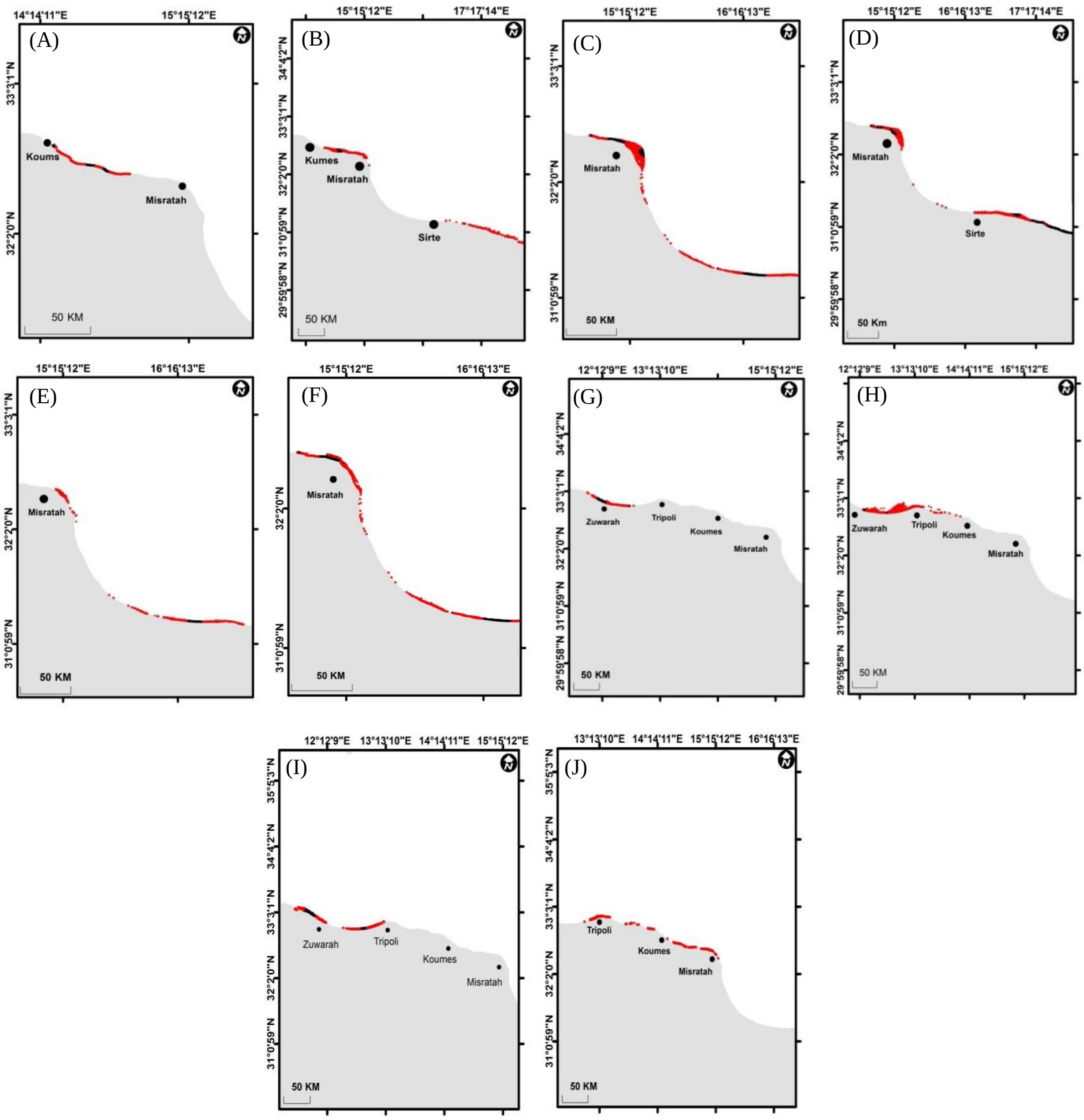


Figure 35 Oil accumulation areas and uncertainty boundary created in GNOME Analyst, (A) presents probabilistic hazard oil spill distribution from hypothetical accidents occurring at the Koums coast in the summer and (B) the winter. Shoreline hazard areas from theoretical accidents occurring at the Misratah coast in the summer can be viewed in (C) and in the winter (D). From hypothetical accidents occurring at the Misratah offshore oil field in the summer seen in (E) and the winter (F). Probability hazard distribution from hypothetical accidents occurring at the Zuwarah coast in the summer is observed in (G) and (H) the winter time (I). Probabilistic hazard oil spill distribution from theoretical accidents occurring at Tripoli offshore oil field in the summer is shown in (I) and (J) the winter season. Red colour presents less probable hazard area than the black colour (best guess outcome).

4.3.3 Tar ball geographic distribution in field observations and simulations

Tar balls may form during the weathering of an oil slick on the sea surface (Chandru et al., 2008). Wind and wave energy at the sea surface influence the size of tar balls (Bacosa et al., 2016). They result from different petroleum sources, but mostly from tanker washing, oil platform accidents and oil and gas industry along the coast (Shirneshan et al., 2016).

The marine area between Libya and Sicily - off the Gulf of Sidra - was recorded by the United Nations for Environment study as having the largest concentration of tar balls in the Mediterranean Sea (Golik, 1988). Tar balls recorded in the study area seem to originate from offshore sources such as operational accidents during oil loading and from the discharge of tank washings and ballast water in oil tankers. The coastal current energy and direction in the Mediterranean Sea can transport tar balls hundreds of kilometres (Kaladharan, et al, 2004) to the Libyan coast, where the dominant direction of Mediterranean current is north to South, while at the Gulf of Sidra current flows in a generally Westerly direction. In the summer, the current direction is generally North-westerly, toward the Gulf of Sidra with a small current recirculation reaching the Libyan coast.

The significance of measuring the position of tar balls is that: (1) Tar balls have direct negative impacts on the shoreline area and associated habitats. (2) The patterns of tar ball distribution can be an indicator of the extent of exposure of coastal habitats to oil pollution. (3) Tar balls give clear evidence for planners communicate and develop coastal protection strategies and (4) Investigation of tar ball distributions at beaches can help validate oil spill simulation results.

This study uses various methods to locate tar balls in affected areas and measure how far they are from the waterline, including GPS and an underwater camera. A total of 41 coastal locations with tar balls and tar residues were measured over the survey period.

The details of the fieldwork observations are presented in Appendix 3 Table 9, where the location of the tar balls is reported along the shoreline area. The table shows that most of the tar ball pollution is spread along the North coast, with fewer tar balls reaching the Eastern coast, especially on rocky shore areas. Tar balls are commonly found around oil spill sources such as the Gaser-ahmed area. Survey observations included tar ball locations between 1 m to 20 m from the seawater line. For example, tar balls were observed 20 m from the sea at the Dafnia beaches. However, at the Mahaboly beach on the Eastern coast, tar balls occurred only 1m from the sea. Such variation in shore position can be due to the influences of wave energy and shoreline topography on oil deposition.

The tar ball distribution map (Figure 37A) shows that most of the oil spill locations mapped during the field survey were spread along the North coast at 29 locations in a 50 km stretch from Dafnia to Gaser-ahmed, concentrated on the rocky shores near oil spill resources such as harbours and oil platforms. In addition, small bays and semi-closed beaches at the shoreline were common areas for oil accumulation, as described in more detail in Chapter One and Two, whereas for the Eastern shore, tar ball pollution was not observed for most of the shoreline area (Figure 37B). Deposition of oil residues was seen in only 11 locations, concentrated in two shoreline segments around the Gaser-ahmed and the Mahaboly beaches.

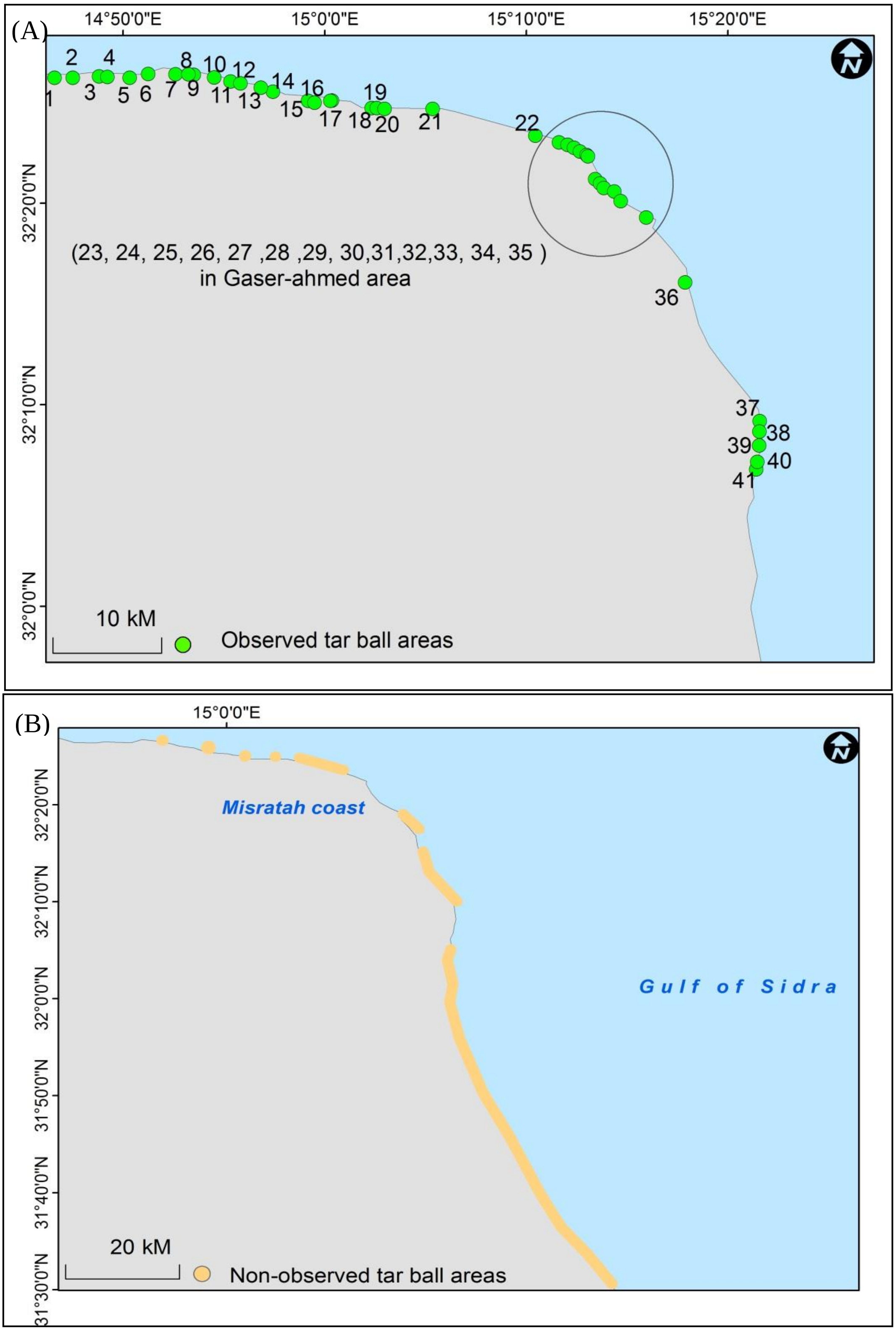


Figure 36 Results of tar ball surveys along the Misratah shoreline. (A) Gives an idea of geographical locations of tar ball pollution on the Misratah shore, (B) shows areas where there were no tar balls observed.

The maps of oil spill movement and potential oil slick deposit areas show that they are closely aligned with the observed tar ball locations (Figures 30-35). The simulation results emphasize that slicks hit the North shore area. The oil spill simulation and observation maps confirm that the Gaser-ahmed shoreline is a potential high oil deposition area; this is due to the proximity of the beaches to oil industry sites and oil tanker lanes in the sea. However, some variability between simulation and observation maps is likely. In any particular spill, the landing point and time of a spill will reflect physical and chemical weathering processes, details of transport and the timing of the oil spill.

Finally, the investigation aimed to confirm indices of coastal vulnerability to an oil spill by combining information about tar ball polluted areas and the results of oil spill modelling. The oil slick movement and the oil deposition area in the simulation align with the results of the coastal tar ball observations and their geographic distribution along the shoreline. Thus, this study provided an opportunity to understand the capabilities of the GNOME model and the utility of this model for predicting possible spill scenarios and to inform oil response strategies along Libyan coastal and marine areas.

4.4 Conclusion

Oil spill accidents at the coast may be increasing and a large number of oil tankers move across the Libyan marine environment (Ciappa and Costabile, 2014; Katsanevakis et al., 2014). Associated oil spill impacts depend on the rate of the spill, the type of spill, the location of the spill, and the influence of wave and current energy on oil movement on the sea surface. This chapter developed scenarios from two types of oil spill: onshore oil spill coming from urban areas and industrial activity on the Misratah coast, and offshore oil spill from the oil industry and tanker traffic.

Modelling is an essential component of coastal risk assessments as it can help guide and scale the mobilization of resources, prioritise coastal and marine protection and mitigation plans, and inform management decisions. Likely oil spill sources were combined with meteorological and oceanographic data to model a series of oil spill accidents in the western coast of Libya.

This work provides seasonal oil spill movement maps for the Western coast of Libya and the Misratah coast. These maps show that oil slick movement on the coast is controlled by prevailing winds and current eddies in the Gulf of Sidra. Therefore, an oil slick might reach the shoreline area in two to thirty days in the summer and winter. Moreover, the model results show that the north coast is the most likely oil deposit area on the Misratah coast.

In particular, oil slicks are expected on the rocky shore around Gaser-ahmed area; the rest of the Eastern coast is at a lower potential oil spill risk. Gaser-ahmed is not the only area at risk, as the Mahaboly coastal zone at the Eastern end of the shoreline is threatened by oil slicks. The map of field observations of tar balls corresponds with the oil spill modelling result, as tar ball pollution was observed along the North coast of Misratah. However, tar balls were recorded on the Eastern shore of Misratah on the Gaser-ahmed and Mahaboly beaches. Finally, coastal oil spill pollution may also originate from the offshore area from different sources including operation accidents in oil platforms, the discharge of tank washings and ballast water in oil tankers.

Chapter 5: Coastal zone mapping strategies for oil spill response

5.1 Introduction

Coastal system management and oil spill pollution are the focus of many national and international projects. Developing scientific and technological tools for oil spill management is essential for making decisions quickly and responding effectively when a spill occurs (Pourvakhshouri and Mansor, 2003). By studying the locations of potential oil sources and sensitivity of the coast to oil pollution, it is possible to create strategies for oil spill response in a study area (Gupta et al., 2002).

This study reviews the progress in Libya’s management of oil spill from coastal socio-economic activity and the offshore oil industry, and discusses the status quo and problems regarding marine oil spill management for Misratah. This information is mapped for the coastal zone to develop strategies for oil spill response**.** A coastal mapping atlas can be used to highlight areas sensitive to oil spills and to highlight potential oil spill sources. These maps can be used to prioritize management and mitigation, identify coastal vulnerability and promote sustainable coastal zone management. Moreover, the priorities of this strategy are to develop operational maps on different geographic scales to provide detail that includes sensitive area boundaries, oil spill location, and coastal resources under oil spill risk. The strategic maps provide information about the various types of coastal areas that may be affected by a spill, such as sand beaches, rocky shore and wetland, so a planner can request the clean-up equipment that best suits the environment.

5.1.1 Definition of existing situation

Coastal oil spill management, providing advisory services to planners and authorities and preparing an effective response plan, has become mandatory both for environmental protection and to fulfil international commitments (Lee and Jung, 2013,). Most Mediterranean countries, including Spain, Italy Greece and Malta applied a coastal sensitivity mapping method to protect coastal areas (Liu, 2010; Castanedo et al., 2009). However, oil spill contingency plans have not been attempted yet in Libya. The Libyan Environment General Authority (EGA) is currently drafting a national oil spill strategy plan (SeaAlarm, 2006, Environment general authority, 2017). Therefore, there has been no coordinated response to oil accidents in ports or on oil platforms (SeaAlarm, 2006). Moreover, poor coastal infrastructure and a lack of management facilities might lead to increases in oil spill impact on coastal resources and habitats and make the oil spill more complicated and harder to remove.

The central Mediterranean is an area of high oil traffic (Janeiro et al., 2014) due to oil tanker traffic between export ports in North Africa and import ports in Southern Europe. For example, in 2010, Libyan crude oil production was 1.8 m b/day; in the region the major export is Libyan oil: 376.000 b/d to Italy, 205,000 b/d to France and 136.00 to Spain, with the rest going to other European countries via the Mediterranean Sea (OPEC, 2013).

The results of the fieldwork study presented in earlier chapters show that oil spills come from different sources such as industrial discharge, oil tanker incidents, and domestic sewage and seaport activities. For example, in 2014, 1000 m^3 of heavy oil were spilt when an accident happened through failures in oil loading and uploading operations. Similarly, in 2006 a large spill was recorded from the CAPTAIN TAKIS ship, which was loaded approximately 29,220 m^3 of oil, totalling spill of over 206 m^3 (Coastal Environmental Protection Department, 2007). In 2013, 200 m^3 of oil infiltrated the sand and rocks of the shoreline when an oil spill happened in the linked oil pipes between oil platforms and oil storages in Gaser-ahmed (Safety and Environmental Unit, 2014).

Although the current work concentrates on oil spill issues, the Misratah coast suffers from other coastal issues such as waste pollution, cooling water pollution, coastal development and sewage pollution, which makes the coastal situation more complicated. The coast needs more integrated approaches to managing coastal resources such as wetlands, sea turtle nesting areas and coastal aquifers. An oil spill strategy was applied on the Misratah coast in an attempt to address the following points:

- The Misratah coastline faces serious problems of habitat destruction by tar balls, oil spill and resource depletion (Patruno, 2004),
- There has been a lack of information and baseline data, uncoordinated laws, and a lack of coordination between administrative bodies.

- The coastline has international importance, particularly migratory turtles and water birds on the eastern coast.

5.1.1.1 Potential oil spill sources

5.1.1.1.1 Oil loading / uploading platform

An oil platform sponsored by the Braga Petroleum Company, the company established to deal with marketing and distributing petroleum products in Misratah, has the second largest oil storage capacity in Libya, at 1×10^6 m^3 (Abomadina, 2002). Additionally, every 30 days, approximately 20 oil tankers carrying around 4 million m^3 of crude and heavy oil enter the Misratah oil platform area from different ports on the Mediterranean coast. Most of reported oil spilt from the Misratah platforms was due to operational failures and human error. The institutions responsible for oil spill and involved in any response strategy are as follows:

- Oil Braga office
- Environmental General Authority
- Libyan Ports Company
- Coast guard

5.1.1.1.2 Fishing and port activity

According to fishing activity in the Misratah coast, there are 13 landing sites recorded along the study area containing more than 300 boats; half of the boats were found in the Gaser-ahamed port, which is located near the Misratah wetland. Although Libya is a signatory of most of the environmental laws and oil spill protocols for the Mediterranean Sea countries and the United Nations, most of the Misratah ports suffered oil pollution due to the lack of oil spill monitoring in Libyan ports and poor infrastructure. For example, there are no recycled oil storages for used oil, thus the used oil may be released illegally at the coast and into the marine environment. The involved responsible institutions in the Misratah oil spill response strategy are as follows:

- Environmental General Authority.
- Coast guard.

5.1.1.1.3 Oil tankers

The average of oil production before 2011 was over 1.65 million b/d, with five refineries and a total capacity of 378 thousand b/d spread along the Libyan coast. Typically 84% of the Libyan crude oil exports through the Mediterranean basin are to the Northern Mediterranean countries (Espon, 2013, UNEP, 2008) via pipelines and oil tankers to Europe, including Italy 28%, Greece 5%, Spain 10%, France 15% and Germany 10% (National Oil Corporation of Libya, 2016). However, the oil products transported by Libyan oil tankers come from different refineries in the Mediterranean countries. The recorded history of oil spill in Misratah is very limited. According to field work surveys and technical reports, in the past 10 years, just one oil spill event was reported by a local authority in Misratah, when an accident happened in the Misratah port. The involved responsible institutions in the Misratah oil spill response strategy were as follows:

- Oil Braga Company.
- Environmental General Authority.
- Coast guard.

5.1.1.1.4 Minor spill at Misratah coast

The Misratah city infrastructure was developed in 1979 for a population of 100,000; by 2015 the population of the city had grown to 400,000 people (Bureau of Statistics and Census Libya, 2016), but the infrastructure capacity remained the same, leading to many issues. The sewage station capacity was only designed for a 100,000 and therefore linked channels between the city and the coast were built to discharge sewage and garbage waste to the sea. This pollution is considered a frequent oil spill resource on the Misratah coast (figure 38). Iron factories and power plants are other oil sources on the Misratah coast (figure 38 D). Because the factory has no strategic plan for oil accidents during operations, they release the oil/mud or oiled water out to sea. Discharging untreated sewage and used oils might lead to significant environmental consequences to coastal habitats and potential impacts on the socio-economic activity along the coast, e.g. the fishing industry, summer resorts, the salt industry and to public health due to pollution mediated pathogens. The involved responsible institutions in the Misratah oil spill response strategy are as follows:

- Water and sewerage office
- Iron and steel industry complex (Iron factory, power plant)
- Environmental General Authority
- Libyan Ports Company

Figure 37 Minor oil spill at Misratah coast, (A, and B) provide an account of used oil coming through sewage pipes, approaching sea water as shown in (C). Figure (D) present picture of oil blow out from power generation plant to the beach without recycling.

5.1.2 Prospective user groups of the operational maps

To meet the challenges of oil spill management, the Libyan government has issued a series of laws and regulations related to the impact of oil pollution on the coastal and marine environment; Libya has also signed international protocols with Mediterranean Sea countries (Appendix 6). The current study is considered as the first to generate an ESI atlas for the Misratah coast, an approach which can be applied to the entire Libyan coast. The aims are to assist oil spill response teams with controlling coastal pollution and to suggest effective methods to protect coastal habitats along the study area coastline. Overall the approach develops a strategy to describe the actions of an oil management team.

The framework (Figure 39) was designed to meet the requirement of a spill response, with an operator and organizations. The strategy suggests a process for the oil spill management team to prepare the necessary equipment to deal with oil events. After an oil spill event is reported to the Environmental General Authority (EGA), the organization responsible for environmental issues in Libya, the oil spill response team should take action to control the oil spill accident and suggest the effective tool to prevent an oil slick from reaching sensitive areas and coastal resources. The operational maps can be a guideline to help the oil spill response team make a preparedness plan for oil spill mitigation and coastal protection. The ESI atlas can help the team access oil spill location and identify and evaluate the costal resources around the spill. The maps also provide detailed information about coastal sensitivity, coastal resource location and coastal topography. All of these features allow planners to take action to reduce oil spill risk to the coastal area, (Vinogradov, 2013). An ESI atlas provides specific details on how to measure coastal elements at risk in the future (Udoh and Ekanem, 2011). Spill scenarios can help responders to decide which type of oil spill clean-up equipment is best, e.g. boom size (Tri et al., 2015). The operational maps can be used in different oil spill categories, for example, for small spill in harbours or major accidents such as collisions over the sea, the maps can provide information about oil spill behaviour under the location conditions and determine the potential oil spill deposition area. In addition, the index provides current information clearly and concisely to the people who are already involved in the oil spill strategy (Division, 2008) and to local stakeholders with an interest in sensitivity maps and oil spill deposition maps, such as the Libyan Ports Company, General authority of fisheries, conservation authorities, and coastal tourism organizations.

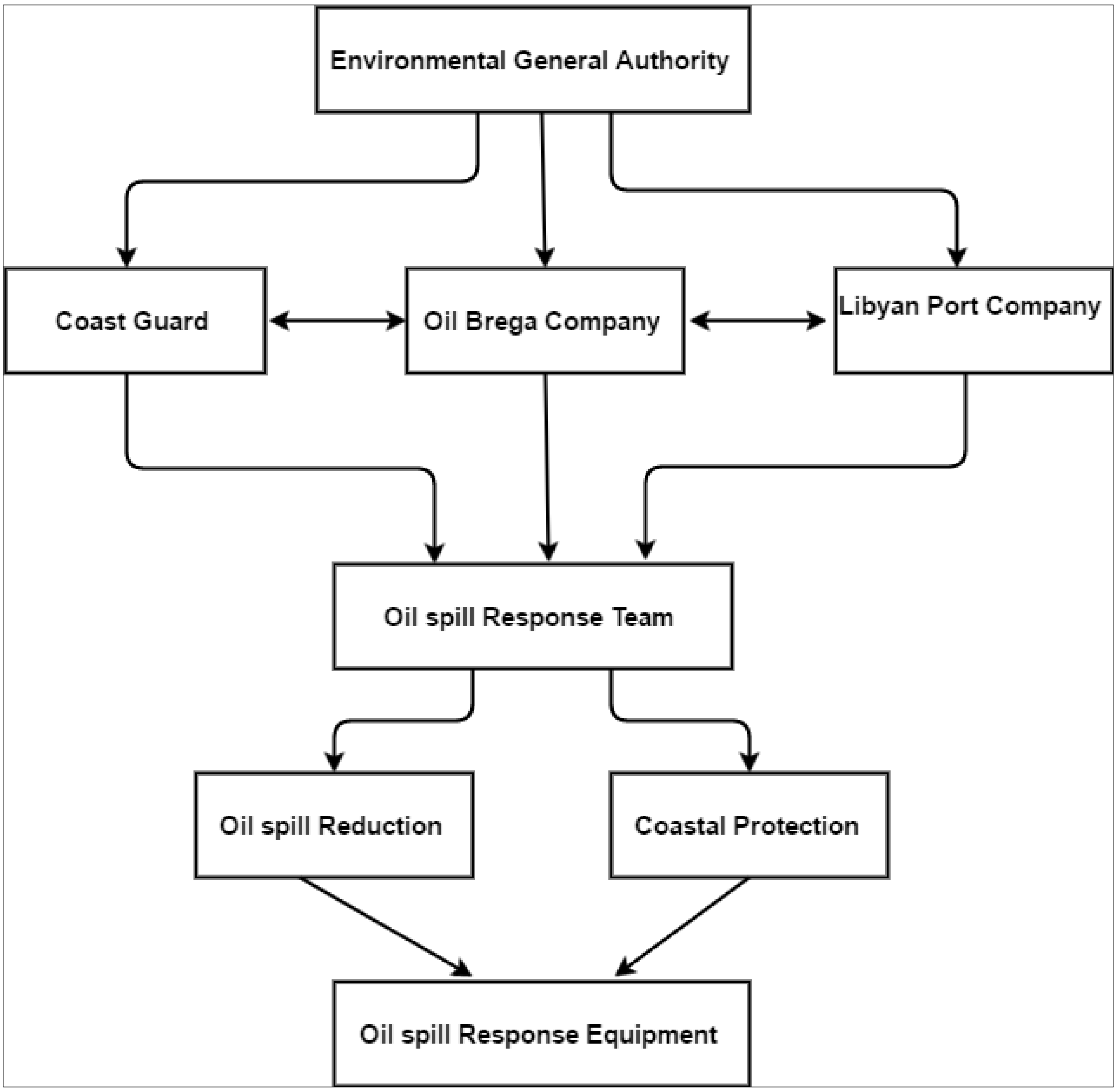


Figure 38 Incident management team structure for oil spill response.

5.2 Model description and methodology

5.2.1 Identification of shoreline risk area during an oil spill

The structure of an oil spill management plan (figure 40) is based on a classification of coastal sensitivity (Singkran, 2013; Frazão Santos et al., 2013; IMO, 2012) and an oil spill simulation database (Azevedo et al., 2017). The framework was developed to supply a tool for developing an objective strategy for oil spill response. The essential objective of this oil spill planning is to reduce the environmental consequences of the spill. This goal is best achieved if the location of sensitive resources and potential oil spill deposition area is identified in advance, streamlining the establishment of protection priorities and clean-up strategy selection.

The environmental sensitivity index (ESI) is widely used for oil spill response in coastal areas. The coastal sensitivity mapping strategy has been prepared for different coastal region across the world. For example, the United States developed 61 atlases covering all the US coastal areas (NOAA, 2017), Canada (Wynja et al., 2015) and on the Gulf of Mexico.

The ESI atlas of Misratah generated from Chapter 3 contains information on sensitive coastal resources to develop strategies for oil spill response, including identification of clean-up equipment needs (Sexton and Murday, 1993; Sealey, 2014). The coastal oil spill strategy proposed is based on two main components: the coastal sensitivity index and the oil spill trajectory database (Chapter 4) (see also Oliveira et al., 2013; Cekirge, 2015). For the planning purposes of this chapter, segments of coastline were identified as belonging to one of four coastal sensitivity index 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). Each map covers a large area and the large scale of the maps show the most important coastal resources. The ESI index shows all of the coastal features in a different colour; this symbology makes the maps a more effective tool for cartographic communication (Jensen et al., 1990). The shoreline hazard (risk) is evaluated based on an analysis of oil spill simulations, accounting for climatological and oceanographic conditions in the study region and expert judgments on the most likely locations for an oil spill. The combination of sensitivity with oil spill risk forms a hazard assessment: an essential step in oil pollution preparedness and response by assisting responders in preparing the equipment required to reduce potential oil spill risk on a coastal area (Wynja et al., 2015). To make the hazard mapping clearer, oil risk index categories were reduced to three groups: high oil risk, medium oil risk, and low oil risk,

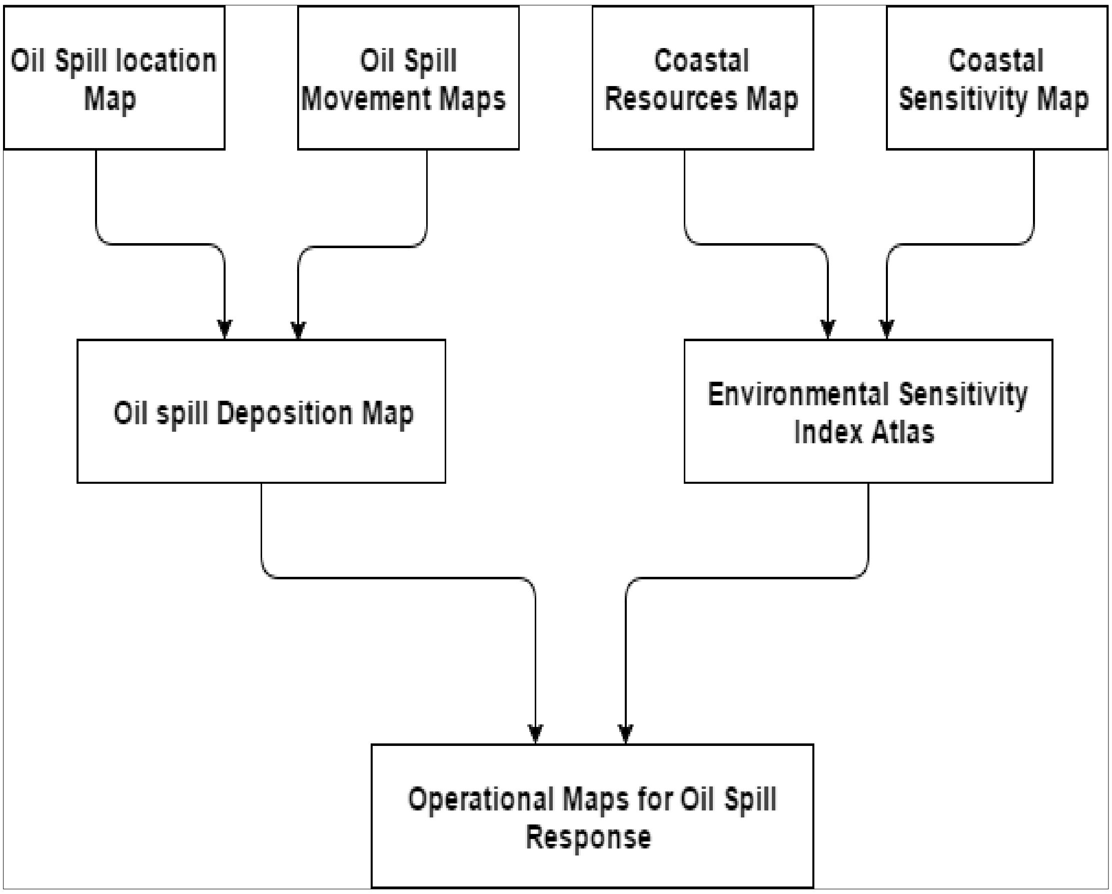


Figure 39 Planning process of the Misratah oil spill strategy, including shoreline hazard index and scheme of the sensitivity index.

5.2.2 Uses of geographic information systems

The Geographic Information System (GIS) is an essential tool for spatial studies, used in emergency planning and decision making during coastal pollution incidents (Nelson et al., 2015). Data needed by the planners, including geographical, shoreline value, clean-up equipment, and oil spill locations, can be acquired and organized in advance through GIS, as can oceanographic information, e.g. winds, wave; current (Ivanov and Zatyagalova, 2008).

With fieldwork observations and an environmental sensitivity index map (ESI), planners can use GIS tools to highlight polluted coastal areas by using attribute table data in ArcMap to create a specific, large scale map that can help the response team during oil spill mitigation (Gorokhovich et al., 2014). GIS tools can also estimate total area covered by an oil spill and estimate the different impact levels of oil pollution from its colour, combined with the preparation of the overall spill area. The ESI information and data can be easily updated and the GIS software can create maps at any scale (Pourvakhshouri and Mansor, 2003). Thus, the strategy designed in this study uses GIS to help the local authority and planners deal with oil spill (Liu et al., 2013) on the Misratah coast. The main purpose of using ArcMap is to store the environmental data and the history of oil spill accidents in Misratah to assist planners with setting a strategy for local accidents. In addition, sharing data with others or uploading data online allows local people and communities to access coastal information (Martin et al., 2004) to increase the environmental awareness about costal ecosystem.

5.3 Results and discussion

5.3.1 Operational maps for oil spill response

The oil spill response plan concentrates on the protection of coastal environments and economically sensitive shorelines. The shoreline response strategy is linked to coastal habitat and resource type and risk from oil spill (Fattal et al., 2010). The operational maps were developed to assist the map user in understanding the environmental situation near an oil spill location, and to investigate coastal resources vulnerable to oil spill movement under local weather conditions. Therefore, the detailed maps in (Appendix 1) were developed to focus on coastal sensitivity to oil spill on the Misratah coast, to present a specific site's protection status and coastal characterization, with all logistical information. The information presented on operational maps is as follows:

- Detailed information to assist planners in an oil spill event, for example access points to spill sites and clean up equipment location.
- Geo-referenced information, including GPS coordinates of the coastal features.
- Baseline information for easily locating the coastal resources and potential oil spill resources without prior knowledge.

5.3.1.1 Coastal sensitivity index area

The ESI maps were developed to describe and document shoreline conditions. These serve as part of the shoreline assessment process in oil spill events, contributing to the development of the response. The coastal habitats and resources covered in the sensitivity maps, such as coastal groundwater, salt marsh, sea turtle nesting area, migrant birds' feeding sites and socio-economic activity sites as shown in the ESI atlas (Appendix 1). In this study, the ESI map was used to provide a contingency plan for local oil spill, 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 highest oil risk locations in the coastal area (Oyedepo, 2011). In addition, the sensitivity index maps can be a support tool for developing new policy for coastal oil contamination and can be used to calculate contaminated areas.

As can be seen in the ESI map, the most highly sensitive shoreline is located on the Eastern coast of Misratah, containing wetlands, feeding places for migrant birds and nesting areas for sea turtles (WWF, 2005). Although there is no offshore or onshore oil activity on the Eastern coast, that area is at risk from oil slick movement due to wind and current directions in the Gulf of Sidra, and maritime transportation between the Misratah oil platforms and oil refineries on the Eastern site of the Libyan coast.

5.3.1.1.1 Very high sensitivity coast (ESI 9)

Very high sensitivity index segments of shore are of several types, including different biological resources and socio-economic activities (Table 6). The highest areas of shoreline sensitivity on the Misratah coast are classified as ESI 9, which includes the most productive section of the coastal area. The high sensitivity to oil spill is due to generally low wave energy and local persistence of oil. The ESI 9 shoreline type predominates on the Eastern coast (Appendix 1, Figures 38-43). The coastal area has high biodiversity because it contains the most environmentally important features in the Libyan coast: wetlands, turtle nesting areas and migratory bird nesting sites.

Table 6 Key to the very high sensitivity shoreline segments of the Misratah coast

Category number	Shoreline segment	Biological index	Socio-economic index	Coast descriptio n
ESI 9 (figure 38)	Buerat	Wetland (Sabkha) Sea turtle nesting area Migratory birds feeding area	Salt industry Swimming sites	Vegetated low Banks
ESI 9 (figure 39)	Alkouda	Wetland (Sabkha) Sea turtle nesting area Migratory birds feeding area	Salt industry Swimming sites Fishing sites	Vegetated low Banks
ESI 9 (figure40)	Almajaran	Wetland (Sabkha) Sea turtle nesting area Migratory birds feeding area	Salt industry Swimming sites	Vegetated low Banks
ESI 9 (figure 41)	Marzouga	Wetland (Sabkha) Sea turtle nesting area Migratory birds feeding area	Salt industry Swimming sites	Vegetated low Banks
ESI 9 (figure 42)	Mahaboly	Wetland (Sabkha) Sea turtle nesting area Migratory birds feeding area	Salt industry Swimming sites Fishing sites	Vegetated low Banks
ESI 9 (figure 43)	Alroumia	Wetland (Sabkha) Sea turtle nesting area Migratory birds feeding area	Salt industry Swimming sites Fishing sites	Vegetated low Banks

5.3.1.1.2 High sensitivity coast (ESI 6B to ESI 7)

The high sensitivity segments in this category (Table 7) are ESI 7, consisting of exposed tidal flats on the Northern coast, and thought to be rich in species. Oil deposited on these flats may remain for long period, according to the observations from fieldwork. These areas are under oil pollution risk due to their proximity to the potential oil spill resources; oil spill might reach the human-use areas on the Aljazeera and Zurek beaches. The riprap beaches (ESI 6 B) are man-made walls and have a moderate to high abundance of species; this shoreline segment has medium-high sensitivity because it is usually subject to high wave and tide energy. Oil could penetrate deeply between the boulders and biological resources would be damaged by the spill. The probability and frequency of a hazard due to an oil spill is high, because most riprap beaches were built near ports and coastal socio-economic sites. Most of these types of shore are also located on the Northern coast. Moreover, this area contains vulnerable resources, such as summer resorts and historical and cultural sites at Zurek, Dafnia and Aljazeera.

Table 7 Key to the representation of high sensitivity segments of the Misratah coast

Category number	Shoreline segment	Biological index	Socio-economic index	Coast description
ESI 6B (figure 33)	Aljazeera	Shoreline species	Gaser-ahmed harbour Summer resort Fishing sites	Riprap beaches
ESI 7 (figure 34)	Dafnia	Intertidal species	Swimming sites Coastal spring	Exposed tidal flats
ESI 7 (figure 35)	Zurek	Intertidal species	Swimming sites Coastal spring Zurek harbour	Exposed tidal flats
ESI 7 (figure 36)	Aljazeera	Intertidal species	Zurek harbour Swimming sites Summer resort	Exposed tidal flats
ESI 7 (figure 37)	Aljazeera	Intertidal species	Swimming sites Coastal spring Fishing sites	Exposed tidal flats

5.3.1.1.3 Medium sensitivity coast (ESI 3 to ESI 5B)

The maps developed contain three basic types of information: shoreline type, biological resources and human-use resources and include high resolution environmental sensitivity data, such as shoreline sensitivity, coastal resources / habitats. The shoreline sensitivity index in (figures 15 - 32), consists of five levels, each having varying levels of sensitivity to oil spill and distinct recommendations for emergency response and clean up. The medium sensitivity classes assigned to the rankings ESI3 to ESI 5B (Table 8) extend along the Misratah coast from Dafnia to Gaser-ahmed. The boulder shore, ESI 5B, is not a common beach type in the study area, described as consisting of boulder sizes from small to large, and is located on the Northern Dafnia shore. Oil could penetrate deeply between rocks. ESI 5A describes irregular protrusions of rocks through sand, extending on the North coast of the Zurek area. The mixed sand and gravel beaches ESI 5 are not common in Misratah and have medium to high permeability to oil and usually low biological productivity. The coarse sand ESI 4A is found in wide intertidal zones, common on the Eastern coast of Misratah, where wave and current are not as strong. Oil persistence may be high and coastal biodiversity such as migratory turtles and feeding sea birds could be under oil spill risk. The ESI 3 shoreline sensitivity level represents fine to medium sandy beaches, not particularly common on the Misratah coast. Such shoreline areas are semi-permeable to oil; therefore oil persistence could be short-term before being removed by wave action and human activity on the beaches.

Table 8 Key to the representation of medium sensitivity segments of the Misratah coast

Category NO	Shoreline segment	Biological index	Socio-economic index	Coast description
ESI 3 (figure 15)	Marzuka	Sea turtle nesting area Migratory birds feeding area	Swimming sites Fishing sites Salt industry	Fine to medium sandy beaches
ESI 3 (figure 16)	Mahaboly	Sea turtle nesting area Migratory birds feeding area	Swimming sites Salt industry	Fine to medium sandy beaches
ESI 3 (figure 17)	Marbat	Shoreline species	Swimming sites Fishing sites Coastal spring	Fine to medium sandy beaches
ESI 3 (figure 18)	Aljazeera	Shoreline species	Summer resorts Coastal spring Swimming sites Fishing sites	Fine to medium sandy beaches
ESI 3 (figure 19)	Aljazeera	Shoreline species	Summer resorts	Fine to medium sandy beaches
ESI 3 (figure 20)	Zurek	Shoreline species	Coastal spring Swimming sites	Fine to medium sandy beaches
ESI 3 (figure 21)	Dafnia	Shoreline species	Swimming sites	Fine to medium sandy beaches
ESI 3 (figure 22)	Dafnia	Shoreline species	Swimming sites	Fine to medium sandy beaches
ESI 3 (figure 23)	Dafnia	Shoreline species	Swimming sites	Fine to medium sandy beaches
ESI 4A (figure 24)	Abofatma	Shoreline species	Swimming sites Historical site Coastal spring	Coarse sand
ESI 4A (figure 25)	Sour-Saud	Shoreline species	Swimming sites Coastal spring	Coarse sand
ESI 5 (figure 26)	Yedder beach	Shoreline species	Swimming sites Coastal spring	Mixed sand and gravel beaches
ESI 5 (figure 27)	Sour-Saud	Shoreline species	Swimming sites	Mixed sand and gravel beaches
ESI 5A (figure 28)	Zurek	Shoreline species	Fishing sites	Irregular protrusions of rocks through sand
ESI 5B (figure 29)	Alromia	Migratory birds feeding area	Swimming sites	Boulder shores
ESI 5B (figure 30)	Gaser-ahmed	coastal species and habitats	Power plant	Boulder shores
ESI 5B (figure 31)	Zurek	Shoreline species	Swimming sites	Boulder shores
ESI 5B (figure 32)	Gaser-ahmed	Shoreline species	Swimming sites	Boulder shores

5.3.1.1.4 Low sensitivity coast (ESI 1 to ESI 2)

The low sensitivity shorelines level (Table 9) is partitioned into 15 coastal stretches; predominantly along the Northern coast with a strip on the Eastern coast. These shoreline areas are characterized as cliff-exposed shoreline area. These areas are classified as ESI 1 and ESI 2 (Appendix 1, figure 1-14), which consist of exposed rocky shores, exposed man-made structures and exposed wave cut platforms alternating with the rocky headland.

ESI 2 represents exposed wave cut platforms; a wave-cut platform or wave-cut bench is the narrow flat area often found at the base of the sea cliff. In the event of an oil spill, oil can remain on the flats and take a long time to remove in sheltered areas. Thus, rocky species and habitats might be damaged. ESI 1A are exposed, man-made structures where species abundance and diversity is low. These areas are located around factories and ports and are exposed to high ocean energy, which pushes oil offshore as waves are reflected from sloping or vertical faces. Finally, the steep and exposed shores that are common on the North Misratah shoreline are represented as ESI 1. This category of shore is exposed to high wave energy and contains few species. These shores can be self-cleaning, again with wave reflection keeping oil offshore.

In summary, the ESI atlas contains human use data (e.g. public beaches, cultural sites and industrial and fishing ports) and these details can show planners how resources might be economically impacted. This means that the maps can help develop protection plans, mitigate coastal environmental damage, and allow authorities to plan around locations of high-value coastal animal populations (Jensen et al., 1998).

Table 9 Key to the representation of low sensitivity segments at Misratah coast

Category number	Shoreline segment	Biological index	Socio-economic index	Coast description
ESI 1 (figure 1)	Gaser-ahmed	Rocky shores habitats Migratory birds feeding area	Salt industry Swimming sites Fishing sites	Exposed rocky shores
ESI 1 (figure 2)	Yedder beach	Rocky shores species and habitats	Swimming sites Coastal spring	Exposed rocky shores
ESI 1 (figure 3)	Marbat	Rocky shores species and habitats	Swimming sites	Exposed rocky shores
ESI 1 (figure 4)	Aboruaia	Rocky shores species and habitats	Swimming sites	Exposed rocky shores
ESI 1 (figure 5)	Abofatma beach	Rocky shores species and habitats	Swimming sites	Exposed rocky shores
ESI 1 (figure 6)	Zurek	Rocky shores species and habitats	Swimming sites	Exposed rocky shores
ESI 1 (figure 7)	Zurek	Rocky shores species and habitats	Swimming sites	Exposed rocky shores
ESI 1 (figure 8)	Dafnia	Rocky shores species and habitats	Fishing sites Swimming sites	Exposed rocky shores
ESI 1A (figure 9)	Gaser ahmed	Man-mad structure species and habitats	Gaser-ahmed Harbour	Exposed man-made structure
ESI 1A (figure 10)	Gaser ahmed	Man-mad structure species and habitats	Power plant	Exposed man-made structure:
ESI 1A (figure 11)	Zurek	Man-mad structure species and habitats	Fishing sites	Exposed man-made structure
ESI 1A (figure 12)	Zurek	Man-mad structure species and habitats	Fishing sites	Exposed man-made structure
ESI 2 (figure 13)	Sour-Saud	Intertidal species and habitats	Swimming sites	Exposed wave cut platform
ESI 2 (figure 14)	Dafnia	Intertidal species and habitats	Swimming sites	Exposed wave cut platform

5.3.1.2 Shoreline hazard index

Although the ESI atlas can inform oil spill response plans on the likelihood and amount of oil pollution in prioritized environmentally sensitive areas, the oil spill simulation database is the key to successful early warning and oil spill emergency response (Azevedo et al., 2014). This study used oil spill movement information (Chapter 4) to develop an oil risk index for an integrated oil spill contingency plan for the Misratah coast.

The oil risk map (figure 41) demarcates the coastal areas under the risk of oil pollution and where socio-economic activity may be affected, including coastal habitats and species. The shoreline oil risk index in the study area is partitioned into three coastal stretches: low, medium and high oil risk. The segments are based on simulations of oil spill (Chapter 4) and on field observations of oil and likely spill sources. The high risk area is concentrated within the Northern and Eastern shoreline from Gaser-ahmed to Aljazeera, while the medium oil risk is spread in the North shoreline from Aljazeera to Dafnia, and from Gaser-ahmed to Buerat shore on the Eastern coast. The lowest risk segment on the Misratah shoreline is on the Eastern coast from Gaser-ahmed to Buerat.

The output of oil spill trajectory mapping in Misratah as presented in Chapter 4 is a strategic tool that helps managers estimate the location of spilt oil and to quantify it. Moreover, a planner can predict where a hazard may occur and how much time an oil slick may take to reach the coast (Bejarano and Mearns, 2015). Therefore, this information allows decision makers to develop a plan for response options that minimize damages to coastal habitats (Assilzadeh and Gao, 2008).

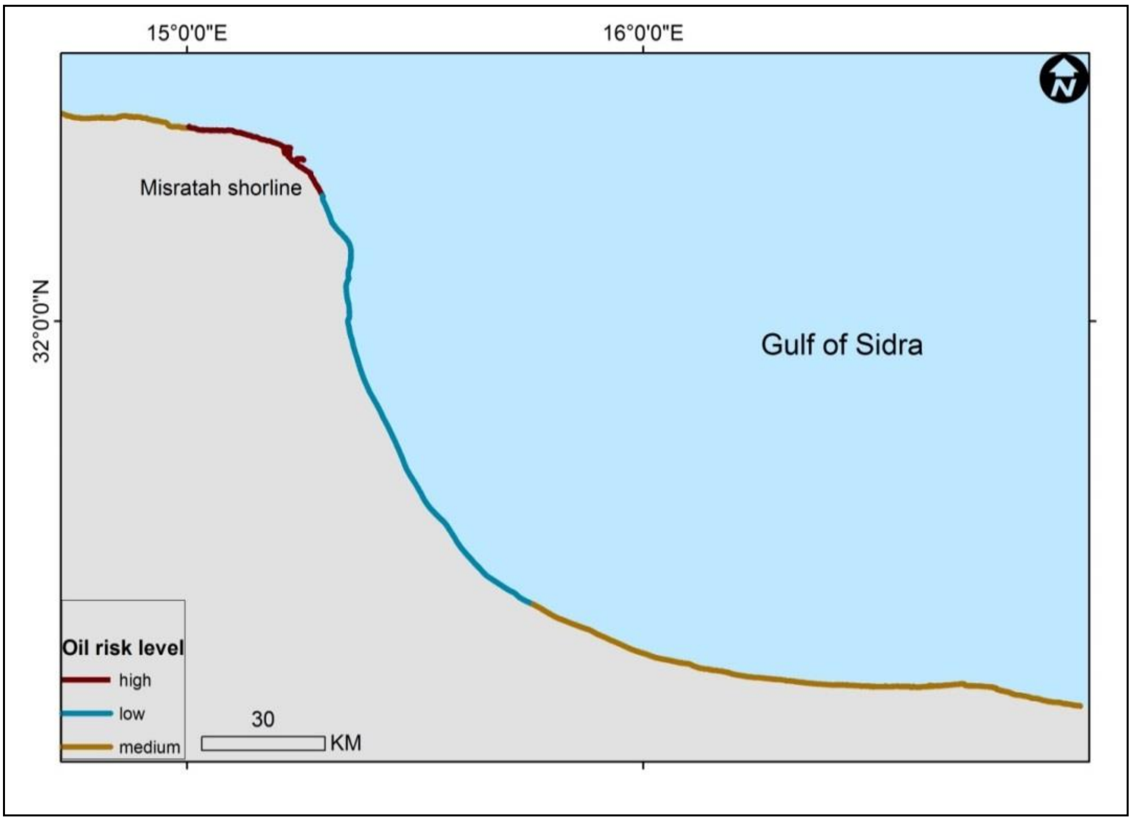


Figure 40 Potential oil spill deposition map based on the GNOME outputs for oil spills at Misratah coast in the summer and winter seasons.

5.3.2 Quantitative oil risk management system for the Misratah shoreline

In order to develop guidelines for an oil spill event, assessments for shoreline segments were established according to their sensitivity level and oil spill risk (Azevedo et al., 2017). An analysis of the coastal segments was carried out, covering 43 sections along 248 km of rocky shores and sandy beaches; 10 shoreline segments defined by ESI index were spread along the Eastern coast, while 33 sections extended along the Northern coast of Misratah. According to the ESI data (appendix 2, tables 1and 2), there are several types of shoreline classes, covering the whole range of the sensitivity index values.

The lowest sensitivity shoreline type includes 14 shoreline segments (Appendix 1 Figures 1-14), classified as ESI1 - ESI 2. The medium sensitivity locations correspond to sandy beaches, classified from ESI 3 – ESI 5B, including 17 shoreline sections distributed along the coast (Appendix 1 Figures 15-32), while the five high sensitivity areas were located on the Northern coast (Appendix 1 Figures 33-37). The very high sensitive areas, ESI 9, were located on the Eastern coast in 6 shoreline segments (Appendix 1 Figures 38-43), representing vegetated low bank on the wetland coast.

In terms of shoreline oil spill risk index, each segment was classified according to oil spill deposition maps in the oil spill simulation, which was divided in three level risks: (1) high, (2) medium and (3) low oil risk (Figure 40). In general, the majority of the Misratah shoreline faces medium oil spill risk along the North and Eastern coast (Appendix 1 Figures 2, 4-8, 11, 12, 14, 20-24, 28, 31, 34, 35, 40), whereas 13 shoreline segments of the Misratah shoreline are under high oil risk, within the area from Gaser-ahmed to the Aljazeera shore (Appendix 1 Figures 1, 3, 9, 10, 13, 17, 18, 19, 26, 27, 33, 36, 37).

The results of a cross-tabulation of risk and sensitivity data illustrate that there are two very high sensitivity shoreline segments (Appendix 1 Figures 40, 38) located in medium oil spill risk areas, with a length of 61 km on the Eastern coast, with very high sensitivity areas absent from high oil risk areas. These very high sensitivity areas at medium risk are clear targets for prioritization in any management plan for oil spill on the coast. 67 km of the very high sensitivity shoreline is under low oil spill risk (Appendix 1 Figures 39, 41-43). The high sensitivity ESI categories included 1 km of the shoreline in the high oil risk area along the North coast in the Aljazeera area (Appendix1 Figures 33, 36).

The exposed tidal flats cover approximately 15 km in the medium oil risk area on the Northern coast of Misratah. The study found medium sensitivity areas under medium oil pollution risk present in 17 km of shoreline on the Northern and Eastern coast (Appendix 1 Figures 17-24, 27, 27, 31). The rest of the medium sensitivity shoreline appears in the low oil risk area and covers 25 km of shoreline (Appendix1 Figures 15, 16, 29).

The geographical scope of the low sensitivity shoreline is between the North and East coast with total length of around 52 km. However, 40 km of the low sensitivity area (Appendix 1 Figures 1-3, 9, 10, and 13) falls in the shores considered at a high-risk according to the oil spill simulation maps, while 11 km of the shoreline is under medium oil spill risk (Appendix 1 Figures 4, 5, 7, 8, 11, 12, 14).

Table 10 Shoreline sensitivity classification under coastal oil risk. Number of coastal segments (Tables 1-4 and figures in appendix) in each category, along with the estimated total length of coastline segments.

Oil risk / ESI level	High risk	Medium risk	Low risk	Total (km)
Very high sensitivity ESI9	0	2 (61.27km)	4 (66.86 km)	128
High sensitivity ESI 6B to 7	2 (1.09km)	3 (14.42 km)	0	16.32
Medium sensitivity ESI 3 to 5B	5 (10km)	10 (17.2 km)	3 (25.47 km)	52.76
Low sensitivity ESI 1 to 2	7 (40.39km)	8 (11.64 km)	0	52.3

The results of the oil risk assessment provide information about the various types of coastal areas that may be affected by a spill, such as sandy beaches, rocky coasts and wetlands, which can help planners to request the clean-up equipment best suited to a habitat. Therefore, these results can be used for oil spill emergency planning and in support of long-term spatial planning decisions for coastal protection by understanding the geographical distribution of oil risk and vulnerability. For example, the results can be provided as a tool for planners to identify resources at risk, with priority areas, and develop an appropriate response to oil clean-up to protect more sensitive areas in a short time frame.

Based on the distribution of potential oil spill resources and the deposition area of an oil spill, four regional oil spill emergency equipment stockpiles can be proposed for set up to support a timely, measured and effective oil spill response. The amount and type of emergency equipment available in each location are based on the potential risk, oil spill size, and coastal resources value and shoreline sensitivity level. For example, regions with major oil activity such as Gaser-ahmed should have larger stockpiles and special equipment.

The geographical locations of emergency equipment is proposed in order to control and prevent spills from spreading to sensitive areas are shown in Figure 42. Two geographic locations on the North coast for equipment stockpiles are in the Gaser-ahmed and Zurek areas, where the majority of socio-economic resources such as tourist beaches, historical and religious sites are located. The oil response equipment including oil spill control tools and spill monitoring equipment should reflect the potential oil spill sources located on the North coast, especially in the Gaser-ahmed area where the majority of recorded oil spill resources are located. These emergency tools can help deal with small-scale accidents occurring in ports, harbours, and oil platforms. In addition, oil containment booms and skimmers are effective tools that can remove an oil slick from the sea surface before it reaches sensitive areas along a coastline and these tools should be placed in two sites on the Eastern coast because this area is recorded as having a high sensitivity to oil spill and is rated at high risk due to oil spill movement and environmental importance as habitats (wetland) for migratory sea turtles and sea birds.

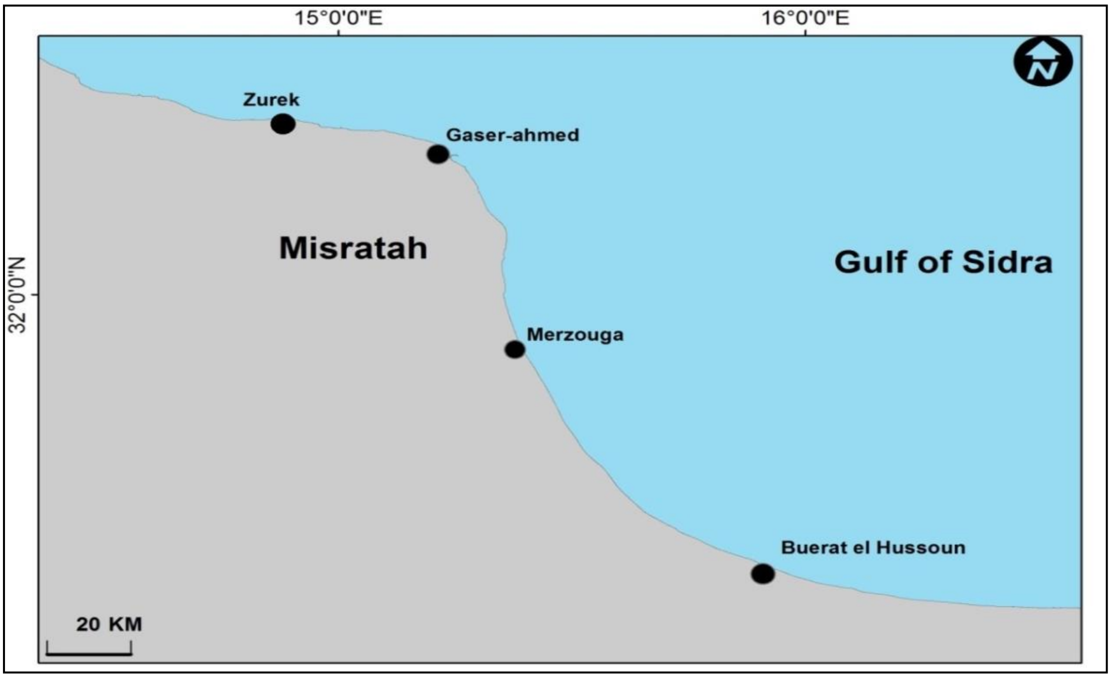


Figure 41 Suggested equipment stockpile locations for managing coastal oil pollution on the Misratah coast.

5.4 Conclusion

Coastal oil pollution is one of the main issues affecting marine coastal environments in Libya. This study developed a mapping strategy for oil spill response, an effective tool for dealing with different coastal sensitivity areas in an oil spill event. The coastal management strategy aims to develop a plan to control the complex interaction between coastal resources and oil contaminants (Liu and Wirtz, 2010). To this end, the guide maps use a needs-based coastal zone mapping strategy for oil spill response to assist planners in understanding the specific requirements of each sensitive area along the coast. The developed strategic maps are considered a response tool during an oil event, providing responders with all required environmental, human-user location and operational information to plan and implement response and protection operations. In addition, the atlas includes additional information such as clean-up technical guidelines and restoration recommendations.

A regional oil risk management system was developed; shoreline segment risk was assessed, based on a shoreline oil risk map and ESI index. Covering 248 km of coastline, the operational maps were obtained from analysis of the ESI index database, generated in the third chapter. The ESI atlas provides large scale, detailed maps that include coastal resources, human use, coastal types and biological resources. The oil risk index was generated from analysis of the oil spill movement scenario database. These databases were compiled and stored using Geographic Information System (GIS), from which hard copy maps are created at different scales depending on their purpose.

The coastal mapping strategy presented herein can provide enhanced information for distinct end-users such as port authorities, oil platform operators and recreational organizations about the coastal condition and resource quality of the coast in the occurrence of an oil disaster.

General conclusions

Oil spills in the Mediterranean Sea are a major and continuous threat to the sensitive coastal zones of the region, especially the coastal zone of Libya, as it harbours many oil platforms and offshore and onshore oil activities. The Libyan coastal and marine area is exposed to a high risk of oil pollution from global oil tankers' routes connecting the Libyan oil exporting ports and the Western basins of the Mediterranean Sea. Frequent oil spills are carried through sewage pipes from urban areas, factories and harbours. The lack of a reliable historical oil spill record, the weak monitoring and response to oil spill make the Libyan coastal resources vulnerable. Therefore, the development of coastal zone management is a necessity to protect shores from oil spills.

During the last five years, one of the Libyan commission's priorities for coastal protection from oil spill in the Environmental General Authority and the Department of Health, Safety & Environment of the National Oil Corporation has been the adoption of a common approach to coastal and marine spatial planning along the Libyan coast. Protection and planning in the coastal zone is a significant strategy for Libya, due to the length of coast, the high rate of oil export, and spills' potential negative impacts on coastal and marine habitats. The research developed in this thesis extended the existing knowledge base by focussing on the Misratah coast. Multiple methods were used to generate a coastal sensitivity atlas bases on the ESI framework.

The second phase of the thesis was to develop a coastal sensitivity index based on a compiled assessment of various processes: physical setting, socio-economic activities, ecological parameters, and types of environmental stress, including oil. The study found that the eastern coast is, in general, more sensitive to oil spill than the northern coast. On a scale from 1-9 in terms of sensitivity to oil spill, the vegetated low banks, ESI 9, covering 128.13 km of the shoreline, were the most sensitive habitat in the and are only found on the Eastern shoreline. The exposed rocky shores ESI 1, covering 27.18 km along the North coast, were the least sensitive shorelines.

The third goal of the work was to identify coastal oil spill sources and create seasonal maps for oil spill movement to understand oil behaviour on the sea surface and to determine areas at risk. Two scenarios for the summer and the winter season were run, along the Western coast of Libya. The study considered oil pollution from different sources: major oil sources come from offshore oil industries and loading/uploading oil platforms, while the minor oil resources come from urban sewage pipes, fishing ports and the iron and steel industry in the Gaser-ahmed area. However, the study also found that oil slick movement on the coast is controlled by prevailing winds and current eddies in the Gulf of Sidra. Therefore, an oil slick might reach the shoreline in two to thirty days in the summer and the winter. Moreover, the model results show that the North coast of Misratah is at a higher risk of oil pollution, while the Eastern coast is at a lower potential risk due to the influence of winds and current energy in the Gulf of Sidra.

A spatial coastal mapping strategy based on the coastal sensitivity index and oil spill simulation data was developed, containing information about the physical character, socio-economic activity and biological resources of the shoreline. The priorities of this strategy included operational maps on different geographic scales to provide a detailed map that includes the sensitive area boundaries, oil spill location, and coastal resources under oil spill risk. The ESI atlas is an essential step in oil pollution preparedness and response, as it can assist responders during an oil incident, and help a planner request the clean-up equipment that best suits the environment. These maps can be used to prioritise management and mitigation, identify coastal vulnerability and promote sustainable coastal zone management. They can assist the user to understand the environmental situation near an oil spill location and to investigate coastal resources vulnerable to oil spill movement under local weather conditions.

The result of coastal oil spill management shows that the majority of the Misratah shoreline faces medium oil spill risk, spread along the Northern and Eastern coast, whereas 14 shoreline segments of the Misratah area are under high oil risk, distributed along the area from Gaser-ahmed to Aljazeera in the North and East coast of Misratah. In particular, the findings of the cross-tabulation of the ESI index and oil risk index illustrate that 60 km of the very high sensitivity shoreline are under medium oil risk, while 67 km of the same category of shoreline is under low risk. The high sensitivity categories were found in 15 km in the medium oil risk area on the Northern coast. The study found that most of the medium sensitivity area is under medium oil pollution risk, with 17 km shoreline on the Northern and Eastern coast and 40km of the low sensitive area spread within the high-risk area.

Recommendations

To decrease oil spill accidents and their impact on sensitive coastal areas a number of suggestions can be made:

(1) The Libyan environmental ministry should update environmental protection laws for illegal oil discharge into the coastal and marine area and set up new policy for oil release through sewage pipes

(2) Regional planning of oil industry sites, power plants, fishing ports, export ports and iron factories in the coastal area to avoid oil spill during operational processes

(3) Monitor the oil pollution near the oil tanker waiting areas and improve the emergency response

(4) Enhance cooperation and information exchange between Misratah authorities related to coastal oil spill with oil and gas companies in Libya, such as Eni oil in and British Petroleum (BP)

(5) Build oil storage for used oil in Misratah commerce and fishing ports

(6) Reduce the oil transportation in the Gulf of Sidra region to decrease oil spill impact on the nearby coastal wetlands, especially sea turtle nesting areas and the resting sites of migratory birds.

Evaluation of findings and future work

The research in this thesis focused on coastal oil spill management on the Misratah coast; the research question investigated oil spill impact on socio-economic activity and physical and biological parameters. The impacts of oil on the rest of the Libyan coast have not been estimated yet, the same issues apply regarding a lack of data about potential oil spill resources, sensitive areas and the environmental situation of protected areas such as wetlands.

The work in this thesis can be developed into communication tools and shorter reports to inform the relevant authorities and populations about oil spills and potential impacts in the region. As yet, it is difficult to evaluate the oil spill risk mapping in chapter 4. Plausible scenarios are described, but only the congruence with tar ball distribution is evidence that oil is not generally reaching the east coast of the region. If a spill were to be accurately reported and monitored, it would be possible to compare GNOME output using the level of parameterization in this thesis to see how the model performs. This would also need high resolution satellite imagery. Results from Xu et al. (2013) indicate that, if the initial conditions are well enough known, GNOME simulations have good agreement with the observed oil trajectories. Strategies and predictions could also be stratified by the type of oil spilt and more detailed studies of weathering. At the moment, the work essentially covers a 'worst case' approach consistent with the minimum regret approach. It seems more likely that lighter oils and weathering will mean that the 30-day trajectories are not reached in all cases.

There are clear knowledge gaps in the mapping and status assessment for biodiversity in the region. Even the information on turtles and birds is only sufficient to establish that important features exist: The population trends are not clearly established and it would be difficult to identify the region-specific impacts given the migratory nature of the species involved and the other environments and habitat effects that the species may be exposed to. Benthic habitats are not well described for the region. It may be possible to use some predictive habitat mapping to suggest distribution of species of importance. This could identify key sites for detailed survey or protection (Reiss et al. 2015). Alternatively, satellite images and appropriate algorithms may be used to identify intertidal and shallow water habitats of interest.

An important structure-providing habitat may be seagrasses. Seagrass beds (found between 1 and 60 m depth) with *Posidonia*, *Cymodocea spp.* and *Zostera spp* are key habitats in subtidal ecosystems in the Mediterranean. This habitat represents a very important marine community protecting seabed sediments and coastal areas from erosion and providing a complex habitat for a wide variety of marine invertebrates and fish. Seagrass beds may also function as important nursery areas for some commercial fish species and have several roles within an ecosystem, including production of organic matter at the base of the food-chain, as a nursery area for numerous species of fish, breeding grounds, spawning grounds and resting areas (Environmental General Authority, 2004). The combination of and offshore oil industry, the absence of oil spill monitoring and a lack of information on seagrass beds collectively threatens these habitats. More research is needed on the impacts, resilience and recovery rates of seagrass beds to oil pollution. Recovery of seagrass beds is not well understood, with inconsistencies between studies (Fonseca *et al*., 2017). Species associated with seagrasses may be vulnerable to oil pollution because of the risk of either direct smothering or the toxic effects of the water-soluble fraction of oil.

Alongside the knowledge gaps on the distribution of biodiversity, little is known of the lethal and sub-lethal effects of the chronic oil pollution in the area. Given the fishing of marine resources for human consumption, an urgent priority should be monitoring of contaminants in commercially-fished populations, alongside ecotoxicological estimates of any possible effects on fish reproduction and population viability. Studies of fish available in Kuwait found polycyclic aromatic hydrocarbons characteristic of hydrocarbon contamination in both locally sourced fish and fish imported from Egypt (Alomirah et al. 2009). The levels in the Kuwait study were, however, still below reference limits for consumption established in the European Union.

There is clearly a lack of data on direct environmental and economic effects of oil spill on the coastal resources. This goes beyond the ecosystem services associated with fishing. The potential ecosystem services associated with seagrass beds are mentioned above. Tourism is detailed in Chapter 2. It is possible to estimate the value that tourists place on a clean environment both in terms of the number of visitors, but also with questionnaire approaches, which can highlight any value placed on environmental quality. Willingness to pay and related approaches can be used to estimate the value that visitors place on beaches. For example, a study in Abu Dhabi looked at issues from harmful algal blooms, including the level of compensation tourists would accept if a beach was closed (Blignaut et al., 2016). If a comprehensive inventory of ecosystem services were to be derived for the region, this would be a valuable tool in communicating the losses from spilt oil and in focussing planning and management decisions.

There is clearly some fortune in the history of development in the region: the most sensitive and biologically important habitats on the eastern coast are not those at most risk. If there were a formal Marine Spatial Planning (MSP) process, this may have been one outcome. As it stands, the work in the thesis sits well within the framework of integrated coastal zone management (ICZM), defined by the EU (2000) as:

'*a dynamic, multidisciplinary and iterative process to promote sustainable management of coastal zones. It covers the full cycle of information collection, planning (in its broadest sense), decision making, management and monitoring of implementation. ICZM uses the informed participation and cooperation of all stakeholders to assess the societal goals in a given coastal area, and to take actions towards meeting these objectives*.'

Clearly there is some overlap between ICZM and MSP. However, most definitions of MSP emphasize the allocation of space as a key element (e.g., Ehler and Douvere 2009: '*MSP is a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas*'). The activities of interest are effectively allocated space by default in the Misratah region. What is required now is communication with stakeholders and building political will to manage the situation. If there were to be new activities in the region, this may be somewhere where MSP could play a greater role.

This thesis addresses problems including a lack of data on spills, biodiversity, impacts and socio-economic activity that are not limited to Libya. Certain features, like the intertidal springs may not have been widely considered in similar studies. However, the approach of a review of prior data and a field trip, followed by classification of shores is robust and a relatively low-resource way of drawing up an initial map and set of priorities. As a decision support tool, the mapping and prioritization are easy to communicate. A potential weakness of the approach is that the mapping and prioritization involves a number of individual expert judgements. Conclusions may therefore differ between investigators. The influence of subjectivity could be investigated using a sample of independent investigators or by using workshops to combine and contrast different views of the coastal oil spill risks.

References

Abascal, A.J., Castanedo, S., Medina, R., Liste, M., 2010. Analysis of the reliability of a statistical oil spill response model. Mar. Pollut. Bull. 60, 2099–2110.

Abdulla A, Linden O, 2008. Maritime traffic effects on biodiversity in the Mediterranean Sea: review of impacts, priority areas and mitigation measures. Malaga, Spain: IUCN Centre for Mediterranean Cooperation; 184 pp.

Abomadina, H. 2002. Libya ports, Libya, publications of the Libyan ports company, 62 pp.

Abuissa,A,. Kalifa,M,. Ramadan,Z,. 2005. Total petroleum hydrocarbons concentration in the gastropod species *Patella coerulea* l. from the western part of the Libyan coast, Marine research Centre – 31pp.

Addo, A., 2014. Coastal Vulnerability Index to Sea Level Rise in Ghana. Coast. Mar. Res. 2, 1–7.

Adler, E., Inbar, M., 2007. Shoreline sensitivity to oil spills, the Mediterranean coast of Israel: Assessment and analysis. Ocean Coast. Manag. 50, 24–34. doi:10.1016/j.ocecoaman.2006.08.016

Al Malek, S. A., Mohamed, M.O., 2005. Environmental impact assessment of off shore oil spill on desalination plant. Desalination 185, 9–30.

Al Shami, A., Harik, G., Alameddine, I., Bruschi, D., Garcia, D.A., El-Fadel, M., 2017. Risk assessment of oil spills along the Mediterranean coast: A sensitivity analysis of the choice of hazard quantification. Sci. Total Environ. 574, 234–245.

Alasady, M., 2012. Levels of oil residues in some coastal lagoons, East of Libya. Mesopotamian J. Mar. Sci. 27, 67–77.

Alhargan , A,.1997. Creation of a coastal zone information system for Qatar using remote sensing and GIS. Unpublished PhD thesis, Southampton University, Southampton 150-190pp.

Alkoja,S,. 2002. Pollution of sea water in western Libya. Unpublished MA thesis. Elmergib University, Libya.75-115pp.

Almabrok, A,. 2004. Fisheries in the Misrata region, a study in economic geography. Unpublished MA thesis, ElMergib University, Libya.

Alomirah, H., Al-Zenki, S., Husain, A., Ahmed, N., Al-Rashdan, A., Gevao, B., Sawaya, W. 2009. Dietary exposure to polycyclic aromatic hydrocarbons from commercially important seafood of the Arabian Gulf. J. Food Agric. Env. 7, 9-15.

Alves, T.M., Kokinou, E., Zodiatis, G., 2014. A three-step model to assess shoreline and offshore susceptibility to oil spills: The South Aegean (Crete) as an analogue for confined marine basins. Mar. Pollut. Bull. 86, 443–457.

Alves, T.M., Kokinou, E., Zodiatis, G., Lardner, R., 2015. Hindcast , GIS and susceptibility modelling to assist oil spill clean-up and mitigation on the southern coast of Cyprus (Eastern Mediterranean) Deep-Sea Research II, 6-9pp.

Aniba, O., 2007. Morphology of Misratah coast. Unpublished MA thesis. Misratah University, Libya. 80-96

Anthony, A., Atwood, J., August, P., Byron, C., Cobb, S., Foster, C., Fry, C., Gold, A., Hagos, K., Heffner, L., Kellog, D.O., Lellis-Dibble, K., Opaluch, J.J., Oviatt, C., Pfeiffer-Herbet, A., Rohr, N., Smith, L., Smythe, T., Swift, J., Vinhateiro, N., 2009. Coastal Lagoons and Climate Change : Ecological and Social Ramifications in US Atlantic and Gulf Coast Ecosystems. Ecol. Soc. 14, 8.

Aps, R., Tõnisson, H., Suursaar, Ü., Orviku, K., 2016. Regional Environmental Sensitivity Index (RESI) Classification of Estonian Shoreline (Baltic Sea). J. Coast. Res. 75, 972–976.

Assilzadeh, H., Gao, Y. 2008. Oil Spill emergency response mapping for coastal area using SAR imagery and GIS. Oceans 2008, 1–6. http://doi.org/10.1109/OCEANS.2008.5151820.

Astiaso Garcia, D., Bruschi, D., Cumo, F., Gugliermetti, F., 2013. The Oil Spill Hazard Index (OSHI) elaboration. An oil spill hazard assessment concerning Italian hydrocarbons maritime traffic. Ocean Coast. Management. 80, 1–11.

Azevedo, A., Oliveira, A., Fortunato, A.B., Zhang, J., Baptista, A.M., 2014. A cross-scale numerical modeling system for management support of oil spill accidents. Mar. Pollut. Bull. 80, 132–147.

Azevedo, A., Fortunato, B., Epif, B., Anio, Ergio Den Boer, S., Oliveira, E.R., Alves, L., De Jesus, G., Ao, J. Gomes, L., Oliveira, A., 2017. An oil risk management system based on high-resolution hazard and vulnerability calculations. Ocean Coast. Management 136, 1–18.

Bacosa, H. P., Thyng, K. M., Plunkett, S., Erdner, D. L., Liu, Z. 2016. The tarballs on Texas beaches following the 2014 Texas City “Y” Spill: Modeling, chemical, andmicrobiological studies. Marine Pollution Bulletin, 109(1), 236–244. http://doi.org/10.1016/j.marpolbul.2016.05.076.

Badejo, O.T., Nwilo, P.C., Waterways, F.I., 2003. Management of oil spill dispersal along the Nigerian coastal areas, Available at: http ://www .oceandocs .org/ bit stream/1834/267/1/241.pdf Accessed 26/05/2016.

Bady,S., 2009. Geographical distribution of resorts in Misurata. Unpublished MA thesis, Misratah University, Libya. 120.

Barbieri, R., Stivaletta, N., Marinangeli, L., Ori, G.G., 2006. Microbial signatures in sabkha evaporite deposits of Chott el Gharsa (Tunisia) and their astrobiological implications. Planet. Space Sci. 54, 726–736.

Barron, M., Podrabsky T., Ogle, S., Ricker W., (1999) Area aromatic hydrocarbons the primary determinant of petroleum toxicity to aquatic organisms, Aquatic Toxicology, Vol.46,(3-4):253-268.

Bashat, H., 2005. Challenge of oil spill response in Egyptian coastal zone overlooking the Mediterranean and the Red Sea. International Oil Spill Conference Proceedings: May 2005, Vol. 2005, No. 1, pp. 559-565.

Basyoni, M.H., Mousa, B.A., 2009. Sediment characteristics, brine chemistry and evolution of murayr sabkha, Arabian (Persian) Gulf, Saudi Arabia. Arab. J. Sci. Eng. 34, 95–123.

Beegle-Krause, C., 2003. NOAA model extended to use nowcast/forecast currents. Oil Spill 1–4.

Begg, A.G.S., Reid, J.B., Tasker, M.L., Webb, A, Waterbirds, S.C., 2013. Assessing the Vulnerability of Seabirds to Oil Pollution : Sensitivity to Spatial Scale. Colon. Waterbirds 20, 339–352.

Bejarano, A. C., Mearns, A. J,. 2015. Improving environmental assessments by integrating Species Sensitivity Distributions into environmental modeling: Examples with two hypothetical oil spills. Marine Pollution Bulletin, 93(1–2), 172–182. http://doi.org/10.1016/j.marpolbul.2015.01.022

Blignaut, J., Mander, M., Inglesi-Lotz, R., Glavan, J., Parr, S. 2016. The amenity value of Abu Dhabi's coastal and marine resources to its beach visitors. Ecosystem Services 19, 32-41.

Boak, E.H., Turner, I.L., 2005. Shoreline Definition and Detection: A Review. J. Journal of Coastal Research. 214, 688–703.

Bourass, E., Baccetti, N., Bashimam, W., Berbash, A., Bouzainen, M., De, A., Galidan, A., Saied, A.M., Yahia, J., Zenatello, M., 2013. Results of the seventh winter waterbird census in Libya, January–February 2011 2006, 20–26.

Brega Oil Company, 2013. Available at http://www.brega.ly/, accessed on 5/1/2013.

Brega Petroleum Marketing Company, 2015. Oil spill accident in the Misratah port, Misratah, safety and environmental department.

Brenner, S., 2015. Oil spill modeling in the southeastern Mediterranean Sea in support of accelerated offshore oil and gas exploration. Ocean Dyn. 65, 1685–1697.

Bureau of Statistics and Census Libya, 2016. Available at http://www.bsc.ly/, accessed on 15/3/2017.

Carracedo, P., Torres-López, S., Barreiro, M., Penabad, E., Leitáo, P.C., Pérez-Muñuzuri, V., 2006. Improvement of pollutant drift forecast system applied to the Prestige oil spills in Galicia Coast (NW of Spain): development of an operational system. Mar. Pollut. Bull. 53, 350–360.

Castañedo, S., Fernandez, F., Medina, R., 2008. Oil spill vulnerability atlas for the Cantabrian Coast (Bay of Biscay, Spain). Int. Oil Spill Conf. Proc.

Castanedo, S., Juanes, J. a., Medina, R., Puente, a., Fernandez, F., Olabarrieta, M., Pombo, C., 2009. Oil spill vulnerability assessment integrating physical, biological and socio-economical aspects: Application to the Cantabrian coast (Bay of Biscay, Spain). J. Environ. Manage. 91, 149–159.

Cekirge, H.M., 2015. Response Strategy and Scenarios for Accidents in Crude Oil and Gas Pipelines, International Journal of Environmental Monitoring and Analysis, 18–25.

Chandru, K., Zakaria, M.P., Anita, S., Shahbazi, A., Sakari, M., Bahry, P.S., Mohamed, C.A.R., 2008. Characterization of alkanes, hopanes, and polycyclic aromatic hydrocarbons (PAHs) in tar-balls collected from the East Coast of Peninsular Malaysia. Mar. Pollut. Bull. 56, 950–962.

Cheng, Y., Li, X., Xu, Q., Garcia-Pineda, O., Andersen, O.B., Pichel, W.G., 2011. SAR observation and model tracking of an oil spill event in coastal waters. Mar. Pollut. Bull. 62, 350–363.

Ciappa, A., Costabile, S. 2014. Oil spill hazard assessment using a reverse trajectory method for the Egadi marine protected area (Central Mediterranean Sea). Marine Pollution Bulletin, 84(1–2), 44–55. http://doi.org/10.1016/j.marpolbul.2014.05.044

Clark, R.B., 2001. Marine Pollution. 5th edition, Oxford, UK: Oxford University Press.

Climatology of global ocean winds (COGOW), 2015. Available at http://cioss.coas.oregonstate.edu/cogow/, accessed on 23/10/2015.

Clusa, M., Carreras, C., Pascual, M., Demetropoulos, A., Margaritoulis, D., Rees, A.F., Hamza, A. a., Khalil, M., Aureggi, M., Levy, Y., Türkozan, O., Marco, A., Aguilar, A., Cardona, L., 2013. Mitochondrial DNA reveals Pleistocenic colonisation of the Mediterranean by loggerhead turtles (Caretta caretta). J. Exp. Mar. Bio. Ecol. 439, 15–24.

Coastal environmental protection department, 2007. Environmental General Authority, Tripoli.

COGOW, 2006. User Manual 1–19, available at http: // cioss .coas .oregonstate .edu/ cogow/, accessed on 23/10/2015.

COGOW, 2016. Available at http://cioss.coas.oregonstate.edu/cogow/, accessed on 24/6/2016.

Convention on the Conservation of Migratory Species of Wild Animals (CSM), 2015. Available at http://www.cms.int/, accessed on 31/3/2015.

Cyprus Coastal Ocean Forecasting and Observing System (CYCOFOS), 2017. Available at http://www.oceanography.ucy.ac.cy/cycofos/offshore.html, accessed on 2/4/2017.

D'Urso, I., Ombrelli, M., Telaroli, P., Calesso, W., Badin, C., Senigaglia, M., Urrutia, C., Sterponi, L., 2015. a Multidisciplinary Approach To the Coastal Protection of Two Archaeological Sites in Lybia. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XL-5/W5, 109–116.

Daffonchio, D., Ferrer, M., Mapelli, F., Cherif, A., Lafraya, Á., Malkawi, H.I., Yakimov, M.M., Abdel-Fattah, Y.R., Blaghen, M., Golyshin, P.N., Kalogerakis, N., Boon, N., Magagnini, M., Fava, F., 2013. Bioremediation of Southern Mediterranean oil polluted sites comes of age. N. Biotechnol. 30, 743–748.

Dalyander, P. S., Long, J. W., Plant, N. G., Thompson, D. M. 2014.Assessingmobility and redistribution patterns of sand and oil agglomerates in the surf zone. Marine Pollution Bulletin, 80(1–2), 200–209.

Clausen D, Johansen K.L., Mosbech A.,, Boertmann, S.W., 2012. Environmental oil spill sensitivity atlas for the west Greenland, coastal zone, 2. Available http://www.dmu.dk/Pub/FR828.pdf, accessed on 12/10/2016.

Dauvin, J.C., 1998. The fine sand *Abra alba* community of the Bay of Morlaix twenty years after the Amoco Cadiz oil spill. Mar. Poll. Bull. 36, 669-676.

Deng, Z., Yu, T., Jiang, X., Shi, S., Jin, J., Kang, L., Zhang, F., 2013. Bohai Sea oil spill model: a numerical case study. Mar. Geophys. Res. 34, 115–125.

Depellegrin, D., Blažauskas, N., Groot, R.S. De, 2010. Mapping of sensitivity to oil spills in the Lithuanian Baltic Sea coast. Balt. J. 23, 91–100.

Division, R.S., 2008. Mapping the environmental sensitivity to oil spill and land use/land cover using spectrally transformed Landsat 7 ETM data12, 1–9.

Douvere, F., 2008. The importance of marine spatial planning in advancing ecosystem-based sea use management. Mar. Policy 32, 762–771.

Douvere, F., Maes, F., Vanhulle, a., Schrijvers, J., 2007. The role of marine spatial planning in sea use management: The Belgian case. Mar. Policy 31, 182–191.

Edward H., Owens, 2002. Response Strategies for Spills on Land, Spill Science & Technology Bulletin, Vol. 7, Nos. 3–4, pp. 115–117, 2002

Ehler, C., Douvere, F. 2009. Marine spatial planning: a step-by-step approach toward ecosystem-based management. Paris: UNESCO, Intergovernmental Oceanographic Commission and Man and the Biosphere Programme, IOC Manual and Guides. No. 53, ICAM Doss. 6.

Eiser, W.C,. Kjerfve, B. 1986. Marsh topography and hypsometric characteristics of a South Carolina salt marsh basin. Estuarine, Coastal and Shelf Science 23595-605.

Elabbar, M.M., Elmabrouk, F.A., 2005. Environmental impact assessment for desalination plants in Libya. Case study: Benghazi North and Tobrouk desalination plants. Desalination 185, 31–44.

Elfallah, M., 2005. Program for Assessment and Control of Marine Pollution Strategic Action Programme SAPFor the Libyan Coastal Area. Nation, United Program, Environ. Plan, Mediterr. Action.

El-Geziry, T.M., Bryden, I.G., 2010. The circulation pattern in the mediterranean sea: Issues for modeller consideration. J. Oper. Oceanogr. 3, 39–46.

El-Geziry, T.M.A., 2010. Environmental impact assessment and process simulation of the tidal current energy resource in the Strait of Messina. Unpublished PhD thesis University Edinburgh. Edinburgh, 190-200.

Elghirani , A,. 1981. Occurrence of tar balls on the Libyan beaches. Bulletin of marine Biology Centre- Libyan, 2: 2-14.

El-Hinnawy, M,. Cheshitev, G,. 1975. Geological map of Libya. Tarabulus NI 33-13. Explanatory Booklet. Ind. Res. Cent., Tripoli

Eljabri, A., Gallagher, C., 2012. Developing Integrated Remote Sensing and GIS Procedures for Oil Spills Monitoring at Libyan Coast. 2012 2nd Int. Conf. Environ. Biosci. 44, 17–20. doi:10.7763/IPCBEE.

EMODnet, 2015. Available at http://www.emodnet.eu/, accessed on 5/2/216.

Environmental General Authority, 2004. Marine and coastal resources assessment of the Eastern region of Libya. World Wide Fund Nat, available http://www.uicnmed.or g /web2007/cd2005/conten/doc-2005/libya_biod_report09. 05. Pdf, accessed on 11/5/2014.

Espon, 2013. European Seas and Territorial Development, Opportunities and Risks Governance Case Studies : Mediterranean Sea. ESATDOR 45, available https://www.espon.eu, accessed on 15/1/2016.

Etayeb, K., Essghaier, M.F., Hamza, A., 2007. Report on an Ornithological Survey in Libya from 3 to 15 February 2007. United Nations Environ.15-22.

EU 2000. Communication from the Commission to the Council and the European Parliament on integrated coastal zone management: a strategy for Europe. Commission of the European Communities COM(2000) 547 final.

Farzingohar, M., Ibrahim, Z.Z., Yasemi, M., 2011. Oil spill modeling of diesel and gasoline with GNOME around Rajaee Port of Bandar Abbas, Iran. Iran J. Fish Sci. 10.

Fattal, P., Maanan, M., Tillier, I., Rollo, N., Robin, M., Pottier, P., 2010. Coastal Vulnerability to Oil Spill Pollution: the Case of Noirmoutier Island (France). J. Coast. Res. 265, 879–887.

Fish Base, 2016. Available at http://www.fishbase.org/search.php , accessed on 12 /8 / 2016.

Foley, M.M., Halpern, B.S., Micheli, F., Armsby, M.H., Caldwell, M.R., Crain, C.M., Prahler, E., Rohr, N., Sivas, D., Beck, M.W., Carr, M.H., Crowder, L.B., Emmett Duffy, J., Hacker, S.D., McLeod, K.L., Palumbi, S.R., Peterson, C.H., Regan, H.M., Ruckelshaus, M.H., Sandifer, P. a., Steneck, R.S., 2010. Guiding ecological principles for marine spatial planning. Mar. Policy 34, 955–966.

Fonseca, M., Piniak, G.A., Cosentino-Manning, N. 2017. Suscepability of seagrass to oil spills. A case study with eelgrass, *Zostera marina* in San Francisco Bay, USA. Mar. Pollut. Bull. 115, 29-38.

Food and Agriculture Organization of the United Nations (FAO), 2016. Available at//www.fao.org/fi/oldsite/FCP/ar/LBY/profile.htm, accessed on 31/3/2016.

Frazão Santos, C., Michel, J., Neves, M., Janeiro, J., Andrade, F., Orbach, M., 2013. Marine spatial planning and oil spill risk analysis: Finding common grounds. Mar. Pollut. Bull. 74, 73–81.

Galil, M.A., El-fergany, E., 2011. Sedimentological Significance and Brine Chemistry of Recent Coastal Sabkha , Northwest Libya. JKAU Mar. Sci. 22, 135–158.

Geng, L., Chen, Z., Chan, C.W., Huang, G.H., 2001. An intelligent decision support system for management of petroleum- contaminated sites. Expert Syst. Appl. 20, 251–260.

GeoExpro, 2016. Available at http://www.geoexpro.com/, accessed on 6/3/2016.

Gerin,R., P.-M. Poulain., I. Taupier-Letage.,C.Millot., S.Ben Ismail., C. Sammari, 2009. Surface circulation in the easternMed- iterranean using Lagrangian drifters (2005-2007). Ocean Sci., 5, 559–574.

Gilliland, P.M., Laffoley, D., 2008. Key elements and steps in the process of developing ecosystem-based marine spatial planning. Mar. Policy 32, 787–796.

Global Ocean Current Models, 2015. Available at http://gnome.orr.noaa.gov/goods, accessed on 12/10/2015

GNOME Online Oceanographic Data Server, 2015. Available at https:// gnome .orr.no a a.gov/goods accessed on 17/11/2015

Golik, A,. 1988. Tar pollution i n the Mediterranean Sea. - United Nations Environment Programme A., (91).

Gorokhovich, Y., Leiserowitz, A., Dugan, D., 2014. Integrating Coastal Vulnerability and Community-Based Subsistence Resource Mapping in Northwest Alaska. J. Coast. Res. 293, 158–169.

Grant, A., Briggs, A.D., 2002. Toxicity of sediments from around a North Sea oil platform: are metals or hydrocarbons responsible for ecological impacts? Mar. Environ. Res. 53, 95–11

Gugliermetti, F., Cinquepalmi, F., Astiaso Garcia, D., 2007. The use of environmental sensitivity indices (ESI) maps for the evaluation of oil spill risk in Mediterranean coastlines and coastal waters. WIT Trans. Ecol. Environ. 102, 593–600.

Guidi, G., Sliskovic, M., Violante, A.C., Vukic, L., 2015. Best available techniques (BATs) for oil spill response in the Mediterranean Sea: calm sea and presence of economic activities. Environ. Sci. Pollut. Res.

Gundlach, E.R., Hayes, M.O., 1978. Vulnerability of coastal environments to oil spill impacts. Mar. Technol. Soc. J. 12, 18–27.

Gupta, A K., Suresh, I. V, Misra, J., Yunus, M., 2002. Environmental risk mapping approach: risk minimization tool for development of industrial growth centres in developing countries. J. Clean. Prod. 10, 271–281.

Hamza A, 2010. Sea turtles in the Mediterranean Sea: distribution, threats and conservation priorities. IUCN, Gland, p 157−170

Hanna, R.G.M., 1995. An approach to evaluate the application of the vulnerability index for oil spills in tropical red sea environments. Spill Science and Technology Bulletin 2, 171–186.

Harvey, N., Clouston, B., Carvalho, P., 1999. Improving Coastal Vulnerability Assessment Methodologies for Integrated Coastal Zone Management : an Approach from South Australia. Aust. Geogr. Suties 37, 50–69.

Hayes, M.O., J. Michel, and D.C. Noe. 1991. Factors Controlling Initial Deposition and Long-Term Fate of Spilled Oil on Gravel Beaches. Proceedings, 1991 International Oil Spill Conference. American Petroleum Institute, Washington, DC. pp. 453-460.

Hayes, M.O., J. Michel, D.C. Noe. 1991. Factors Controlling Initial Deposition and Long-Term Fate of Spilled Oil on Gravel Beaches. Proceedings, 1991 International Oil Spill Conference. American Petroleum Institute, Washington, DC. pp. 453-460.

Holden, V., Council, S., 2008. Coastal Defence Report on the Salt Marshes at. United Nations Environ. Program. 44.

Hose, J.E., McGurk, D., Marty, G.D., Hinton, D.E., Brown, E.D., Baker, T.T. 1996. Sublethal effects of the Exxon Valdez oil spill on herring embryos and larvae: Morphological, cytogenetic and histopathological assessments, 1989-1991. Can. J. Fish. Aquat. Sci. 53, 2355-2365.

Hycom, 2017. Available http://www.hycom.org, .accessed on 13/6/2017

IMO, I., 2012. Sensitivity Mapping for Oil Spill Response. London, United Kingdom: PIECA/IMO/OGP. OGP Report Number 477.

Industrial Research Centre, 1975. Misratah geological map, Tripoli, geological survey department.

Islam, M.S., Tanaka, M., 2004. Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: A review and synthesis. Mar. Pollut. Bull. 48, 624–649.

Ivanov, a. Y., Zatyagalova, V. V., 2008. A GIS approach to mapping oil spills in a marine environment. Int. J. Remote Sens. 29, 6297–6313.

Janeiro, J., Zacharioudaki, A., Sarhadi, E., Neves, A., Martins, F., 2014. Enhancing the management response to oil spills in the Tuscany Archipelago through operational modelling. Mar. Pollut. Bull. 85, 574–589.

Jensen, J.R., Halls, J.N., Michel, J., Carolina, S., 1998. A Systems Approach to Environmental Sensitivity lndex (ESI) Mapping for Oil Spill Contingency Planning and Response 64, 1003–1014.

Jensen, J.R., Ramsey, E.W., Carolina, S., Holmes, J.M., Michel, J.E., Savitsky, B., Davis, B.A., 1990. Environmental sensitivity index ESI) mapping for oil spills using remote sensing and-geographic information system technology 4, 181–201.

Jordi, A., Ferrer, M.I., Vizoso, G., Orfila, A., Basterretxea, G., Casas, B., Àlvarez, A., Roig, D., Garau, B., Martínez, M., Fernández, V., Fornés, A., Ruiz, M., Fornós, J.J., Balaguer, P., Duarte, C.M., Rodríguez, I., Alvarez, E., Onken, R., Orfila, P., Tintoré, J., 2006. Scientific management of Mediterranean coastal zone: A hybrid ocean forecasting system for oil spill and search and rescue operations. Mar. Pollut. Bull.

Kaladharan, P., Prema, D., Nandakumar, A., Valsala, K. K. 2004. Occurrence of tarball and waste materials on the beaches along Kerala coast in India. J.Mar.Biol.Ass,India, 46(September 2001), 93–97.

Kankara, R.S., Subramanian, B.R., 2007. Oil Spill Sensitivity Analysis and Risk Assessment for Gulf of Kachchh, India, using Integrated Modeling. J. Coast. Res. 235, 1251–1258.

Katsanevakis, S., Coll, M., Piroddi, C., Steenbeek, J., Ben Rais Lasram, F., Zenetos, A., Cardoso, A. C. 2014. Invading the Mediterranean Sea: biodiversity patterns shaped by human activities. Frontiers in Marine Science, 1(September), 1–11. http://doi.org/10.3389/fmars.2014.00032.

Khanna, S., Santos, M.J., Ustin, S.L., Koltunov, A., Kokaly, R.F., Roberts, D. a, 2013. Detection of salt marsh vegetation stress and recovery after the Deepwater Horizon Oil Spill in Barataria Bay, Gulf of Mexico using AVIRIS data. PLoS One 8, e78989. doi:10.1371/journal.pone.0078989.

Kim, T.-H., Yang, C.-S., Oh, J.-H., Ouchi, K. 2014. Analysis of the contribution of wind drift factor to oil slick movement under strong tidal condition: Hebei Spirit oil spill case. PloS One, 9(1), e87393.

Kingston, P.F., 2002 Long-term environmental effect of oil spills. Spill Science and Technology Bulletin 7, 53-61.

Klemas, V., 2010. Tracking Oil Slicks and Predicting their Trajectories Using Remote Sensors and Models: Case Studies of the Sea Princess and Deepwater Horizon Oil Spills. J. Coast. Res. 265, 789–797.

Knecht and Archer. 1993. Integration in the US coastal zone management program. Ocean & Coast Manage 21: 183– 199.

Krishnamurthy, R.R., DasGupta, R., Chatterjee, R., Shaw, R., 2014. Managing the Indian coast in the face of disasters & climate change: a review and analysis of India's coastal zone management policies. J. Coast. Conserv. 18, 657–672.

Labelle, R.P., Rainey, G., Lanfear, K.J., 1982. An Application of a Vulnerability Index to Oil Spill Modeling in the Gulf of Mexico. US Geol. Surv.

Laurent, L., Bradai, M.N., Hadoud, D. a., El Gomati, H.M., Hamza, A. a., 1999. Marine turtle nesting activity assessment on Libyan coasts. Phase 3: survey of the coast to the west of Misratah. Mar. Biol. Res. 35.

LDK, I.M. de l'Eau, 2013. Update Priority Investment Projects for Protecting the Mediterranean Sea from Pollution, Union for the Mediterranean, Athens.16- 18.

Lee, M., Jung, J.-Y., 2013. Risk assessment and national measure plan for oil and HNS spill accidents near Korea. Mar. Pollut. Bull. 73, 339–44.

Lefond, S., 1969. Handbook of World Salt Resources. New York.

Libya Shipping Agency, 2016. Available at http://www.libiya-shipping.com/LI.htm, accessed on 10/9/2016.

Libya Star for Salt, 2017. Available at http://libyastarsalt.com/?page_id=170 accessed on 12/11/2016.

Libyan Iron and Steel Company, 2016. Available at https: //www .libyansteel .com /in d ex.php/en/ accessed on 13/10/2016

Libyan Water Authority, 2006. Water resources situation, Tripoli.

Liu, R.Z., Borthwick, A.G.L., Lan, D.D., Zeng, W.H., 2013. Environmental risk mapping of accidental pollution and its zonal prevention in a city. Process Saf. Environ. Prot. 91, 397–404.

Liu, X., 2010. Integrated modeling of oil spill response strategies: a coastal management case study. Environ. Sci. Policy 13, 415–422.

Liu, X., Wirtz, K.W., 2010. Managing coastal area resources by stated choice experiments. Estuar. Coast. Shelf Sci. 86, 512–517.

LLP, G.L.H., 2010. Oil Spill Trajectory Modeling Report in Burrard Inlet for the Trans Mountain Expansion Project. GENWEST Tech. Rep. 130.

Mahapatra, M., Ramakrishnan, R., 2015.Coastal vulnerability assessment using an alytical hierarchical process for South Gujarat coast, India. Nat. Hazards 139–159.

Maitieg, A,. 2004. Indications of pollution by tar and sewage; and their geographical distribution in shores of Misratah. Unpublished MA thesis, University of Misratah. Libya.90-85.

Manach, F. Le, Harper, S., Harris, A., Hosch, G., Lange, G.M., Strub, A.M., Zeller, D., Sumaila, U.R., 2015. Reconstruction of Marine Fisheries catches for Libya (1950-2010). Univ. Br. Columbia 1–29. Available at http://www .seaaroundus .org/ doc / publications/wp/2015/Khalfallah-et-al-Libya.pdf, accessed on 12/5/2015.

Mariano,AJ., Kourafalou, VH., Srinivasan, A., Kang, H., Halliwell, GR,. 2011. on the modelling of the 2010 Gulf of Mexico oil spill. Dyn Atmos Oceans 52(1): 322–340

Marine Regions, 2017. Available at http://www.marineregions.org/about.php, accessed on 2/4/2017.

Martin, P.H., LeBoeuf, E.J., Daniel, E.B., Dobbins, J.P., Abkowitz, M.D., 2004. Development of a GIS-based Spill Management Information System. J. Hazard. Mater. 112, 239–252.

MEDPAN , 2013. Available at http://www.medpan.org/en/organisation accessed on 25/2/2015

Mendoza-Cantú, A., Heydrich, S.C., Cervantes, I.S., Orozco, O.O., 2011. Identification of environmentally vulnerable areas with priority for prevention and management of pipeline crude oil spills. J. Environ. Manage. 92, 1706–1713.

Menna, M., Poulain, P.M., 2009. Mediterranean subsurface circulation estimated from Argo data in 2003–2009. Ocean Sci. Discuss. 6, 2717–2753.

Merken, R., Deboelpaep, E., Teunen, J., Saura, S., Koedam, N., 2015. Wetland Suitability and Connectivity for Trans-Saharan Migratory Waterbirds. PLoS One 10, e0135445.

Michel, J., Hayes, MO., Brown, PJ., 1978. Application of an oil spill vulnerability index to the shoreline of lower cook inlet, Alaska. J Environ Geo 2(2):107–117. doi:10.1007/bf02380473

Mohammed, B., Milad, M., 2010. Wind load characteristics in Libya. World Acad. Sci. Eng. Technol. 63, 88–91.

Mumby, P.J., Raines, P.S., Gray, D.A., Gibson, J.P., 1995. Geographic information systems: A tool for integrated coastal zone management in Belize. Coastal Management. 23, 111–121.

National Center for Environmental Information, 2015. Bathymetric Data Viewer, https://maps.ngdc.noaa.gov/viewers/bathymetry/, accessed on 5/2/215.

National Centre for Meteorology, 2017. Available at http://www .lnmc.org.ly/ demo/# currentdatatable , accessed on 15/3/2017.

National Oceanic and Atmospheric Administration, 2015. Available at http://www.noaa.gov/, accessed on 1011/2015

National Oil Corporation of Libya, 2013. Oil production in 2010, production and marketing department, Tripoli.

National Oil Corporation of Libya, 2016. Available at http://noc.ly/index.php/en/ accessed on 5/12/2016

Nelson, J.R., Grubesic, T.H., Sim, L., Rose, K., Graham, J., 2015. Ocean & Coastal Management Approach for assessing coastal vulnerability to oil spills for prevention and readiness using GIS and the Blowout and Spill Occurrence Model 112, 1–11.

Nemirovskaya, I. a., 2011. Tar balls in Baltic Sea beaches. Water Resour. 38, 315–323.

Nezakati,R., Malmas, S., Behrouzirad, B., Esmaeeli, F., 2011. Classification of Miankale Wetland Shore Line Based on Environmental Sensitivity Index (ESI), Irans, 2nd International Conference on Environmental Science and Technology 6, 310–313.

NOAA- STAR, 2015. Available at https://manati.star.nesdis.noaa.gov /datasets /ASC ATData.php accessed on 23/5/2015,

NOAA, 2002. User’s Manual National Ocean and Atmospheric Administration office of response and restoration hazardous materials. Natl. Ocean. Atmos. Available at http://response.restoration.noaa.gov/sites/default/files/GNOME_Manual.pdf, accessed on 23/12/2014.

NOAA, 2002.Environmental sensitivity index guidelines. Technical Memorandum NOS ORR 11, 192 p.

NOAA, 2017. Available at http://celebrating200years.noaa. Gov /foundations /esi_ map /welcome.html, accessed on 15/1/2017.

NOAA-ESI map, 2016. Available at http://response.restoration.noaa.gov/maps-and-spatial-data/download-esi-maps-and-gis-data.html, accessed on 5/12/2016.

Novelli, 2011. Numerical simulation of oil spills in coastal areas using shallow water equations in generalised department of mechanical engineering. Unpublished PhD thesis, Universidad Rovira i Virgil.

Observatory, S. S., 2008. The north-western Sahara Aquifer system (Algeria, Tunisia, Libya) Concerted. General Water Authority (Libya). Available at http://web.cedare.org/wp-content/uploads/2005/05/North-Western-Sahara-Aquifer-System-NWSAS-Monitoring-and-Evaluation-Rapid-Assessment-Report.pdf, accesses on 17/9/2015.

OILmap , 2015. Available at http://www.asascience.com/software/oil map/, accessed on 25/6/2015.

Olita, A., Cucco, A., Simeone, S., Ribotti, A., Fazioli, L., Sorgente, B., Sorgente, R., 2012. Oil spill hazard and risk assessment for the shorelines of a Mediterranean coastal archipelago. Ocean Coast. Manag. 57, 44–52. doi:10.1016/j.ocecoaman.2011.11.006

Oliveira, E.R., Silveira, B., Alves, F.L., 2013. Support mechanisms for oil spill accident response in costal lagoon areas (Ria de Aveiro, Portugal). J. Sea Res. 93, 112–117.

Onofri, L., Nunes, P.A.L.D., Bosello, F., 2013. Economic and climate change pressures on biodiversity in southern Mediterranean coastal areas. MEDPRO - Mediterr. Prospect.

OPEC, 2013. Annual Statistical Bulletin. OPEC, available at http://www.opec.org/opec_web/en/publications/2498.htm, accessed on 19/5/2015.

(ORCA) Office of Ocean Resources Conservation and Assessment, 1997. Environmental Sensitivity Index Guidelines Version 2.0. NOAA.

Oyedepo, J.A., 2011. Environmental sensitivity index mapping of Lagos shorelines. Glob. NEST J. 13, 277–287.

Öztürk, B., 2015. Nature and extent of the illegal, unreported and unregulated (IUU) fishing in the Mediterranean Sea 21, 67–91.

Pashna, M., Yusof, R., Rahmani, R., 2014. Oil Spill trajectory tracking using Swarm Intelligence and Hybrid fuzzy system. IEEE International Conference on Fuzzy Systems (FUZZ-IEEE) 1348-1351.

Patruno, N.M,. Patruno, A.R., 2004. Oil pollution risk assessment and preparedness in the east Memiterran. Tech. Advis. Tanker Owners Pollut. Fed.

Pavin, R,. Ernest,.W, 1982, Sensitivity of coastal environment to spilled oil, south California, NOAA, Washington.

Pezeshki, S.R., DeLaune, R.D., Nyman, J.A., Lessard, R.R., Canevari, G.P., 1995. Removing oil and saving oiled marsh grass using a shoreline cleaner. Int. Oil Spill Conf. 1995, 203–209.

Pincinato, F.L., Riedel, P.S., Milanelli, J.C.C., 2009. Modelling an expert GIS system based on knowledge to evaluate oil spill environmental sensitivity. Ocean Coast. Manag. 52, 479–486.

Poulain, P.-M., Menna, M., Mauri, E. 2012. Surface Geostrophic Circulation of the Mediterranean Sea Derived from Drifter and Satellite Altimeter Data. Journal of Physical Oceanography, 42(6), 973–990. http://doi.org/10.1175/JPO-D-11-0159.1

Pourvakhshouri, S.Z., Mansor, S., 2003. Decision support system in oil spill cases (literature review). Disaster Prev. Manag. 12, 217–221.

Prabhu, K., Kankara, R.S., 2014. Development of mat lab based system to simulate oil spill trajectory using GNOME model for Indian coast. INCHOE, 2014, 5–7.

Ramsar convention 2017. Available at http://www.ramsar.org/, accessed on 15/1/2017.

Reiss, H., Birchenough, S., Borja, A., Buhl-Mortensen, L., Craeymeersch, J., Dannheim, J., Darr, A., Galparsoro, I., Gogina, M., Neumann, H., Populus, J., Rengstorf, A.M., Valle, M., van Hoey, G., Zettler, M.L., Degraer, S. 2015. Benthos distribution modelling and its relevance for marine ecosystem management. ICES J. Mar. Sci. 72, 297-315.

Risien, C.M., Chelton, D.B., 2008. A Global Climatology of Surface Wind and Wind Stress Fields from Eight Years of QuikSCAT Scatterometer Data. J. Phys. Oceanogr. 38, 2379–2413.

Robinson, A.R., Leslie,W.G., Theocharis, A., Lascaratos, A., 2001. Mediterranean Sea circulation. In: Steele, J.H., Thorpe, S.A., Turelian, K. (Eds.), Elsevier, pp. 283–298

Rodríguez-Rodríguez, D., Rodríguez, J., Blanco, J.M., Abdul Malak, D., 2016. Marine protected area design patterns in the Mediterranean Sea: Implications for conservation. Mar. Pollut. Bull. 110, 335–342.

Romero, A.F., Abessa, D.M.S., Fontes, R.F.C., Silva, G.H., 2013. Integrated assessment for establishing an oil environmental vulnerability map: case study for the Santos Basin region, Brazil. Mar. Pollut. Bull. 74 (1), 156–164.

Safety and environmental unit, 2014. Gaser-ahmed port, Misratah 2-6.

Saied, A., Maffucci, F., Hochscheid, S., Dryag, S., Swayeb, B., Borra, M., Ouerghi, A., Procaccini, G., Bentivegna, F., 2012. Loggerhead turtles nesting in Libya: an important management unit for the Mediterranean stock. Mar. Ecol. Prog. Ser. 450, 207–218.

Samaras, A.G., De Dominicis, M., Archetti, R., Lamberti, A., Pinardi, N., 2014. Towards improving the representation of beaching in oil spill models: A case study. Mar. Pollut. Bull. 88, 91–101.

Samuels, W.B., Amstutz, D.E., Bahadur, R., Ziemniak, C., 2013. Development of a Global Oil Spill Modeling System. Earth Sci. Res. 2, 52–61.

Santos, C.F., Andrade, F., 2009. Environmental Sensitivity of the Portuguese Coast in the Scope of Oil Spill Events – Comparing Different Assessment Approaches Journal of Coastal Research, 885–889.

Scott, G.I., Fulton, M.H., Delorenzo, M.E., Wirth, E.F., Peter, B., Pennington, P.L., Kennedy, D.M., Porter, D., Chandler, G.T., Scott, H., Ferry, J.L., 2013. The Environmental Sensitivity Index and Oil and Hazardous Materials Impact Assessments : Linking Prespill Contingency Planning and Ecological Risk, Journal of Coastal Research.6-12.

SeaAlarm, 2006. Country Wildlife Profiles. Profiles, Ctry. Wildl. 1–2, available at http://www.sea-alarm.org/publications/country-wildlife-response-profiles/, accessed on 12/3/2015.

Sealey, 2014. Resources, Methods, and Effort Associated with ESI Mapping of the Bahamian Archipelago for Great Exuma, Bahamas. J. Coast. Res.

Sebastião, P., Guedes Soares, C., 2007. Uncertainty in predictions of oil spill trajectories in open sea. Ocean Eng. 34, 576–584.

Sexton, W., Murday, M., 1993. Environmental sensitivity index mapping of Abu Dhabi (UAE)- A computer based remotely-sensed and field mapping product. Oil Spill Conf. 883–884.

Sharma K., Hichs. D., Rivera W., Vazquez G., 2002. Characterisation and degradation of petroleum hydrocarbons following an oil spill into a coastal environment of south Texas US, Water Air and Soil Pollution, Vol.134, (1-4):111-127.

Shelton, R., Effects of Oil and Oil Dispersants on the Marine Environment. Proceeding of royal society- London. 117:411-422.

Shirneshan, G., Bakhtiari, A. R., & Memariani, M. 2016. Identification of sources of tar balls deposited along the Southwest Caspian Coast, Iran using fingerprinting techniques. Science of the Total Environment, 568, 979–989. http://doi.org/10.1016/j.scitotenv.2016.04.203

Simecek-Beatty, D,. Lehr W. J., 2007. Trajectory Modeling of Marine Oil Spills, Oil Spill Environmental Forensics, pp 405-418

Singkran, N., 2013. Classifying risk zones by the impacts of oil spills in the coastal waters of Thailand. Mar. Pollut. Bull. 70, 34–43.

Singkran, N., Kandasamy, J., 2016. Developing a strategic flood risk management framework for Bangkok, Thailand. Nat. Hazards.

Smart, M., Essghaier, M.F., Etayeb, K., Hamza, A., Azafzaf, H., Baccetti, N., Du Rau, P.D., Dlensi, H., 2006. Wetlands and wintering waterbirds in Libya, January 2005 and 2006. Wildfowl 56, 172–191.

Sowmya, K., Jayappa, K.S., 2016. Environmental sensitivity mapping of the coast of Karnataka, west coast of India. Ocean Coast. Manag. 121, 70–87.

Stelzenmller, V., Lee, J., South, A., Foden, J., Rogers, S.I., 2013. Practical tools to support marine spatial planning: A review and some prototype tools. Mar. Policy 38, 214–227.

Stivaletta, N., Barbieri, R., Picard, C., Bosco, M., 2009. Astrobiological significance of the sabkha life and environments of southern Tunisia. Planet. Space Sci. 57, 597–605.

Szlafsztein, C., Sterr, H., 2007. A GIS-based vulnerability assessment of coastal natural hazards, state of Brazil. J. Coast. Conserv. 11 (1), 53e66.

The General Authority for Marine Wealth in Libya, 2017. Available at, https://agriculture.gov.ly/new/, accessed on 5/1/2017.

The MEDSLIK Oil Spill Model for the Maltese Islands, 2015. Available at http://www.capemalta.net/, accessed on 5/12/2016.

The NOAA Ocean Watch, 2015. Available at http//oceanwatch.pifsc.noaa.gov/ 159, accessed on 20/9/2015.

The Operational Oceanography Group-IAMC, 2015. Available at http://www.seaforecast.cnr.it/forecast/it/content/scrm, accessed on 1/9/2015.

The Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea REMPEC, 2017. Available at http://www.rempec.org/, accessed on 15/1/2017.

Tri, D.Q., Don, N.C., Ching, C.Y., Mishra, P.K., 2015. Application of environmental sensitivity index (ESI) maps of shorelines to coastal oil spills: a case study of Cat Ba Island, Vietnam. Environ. Earth Sci. DOI 10.1007/s12665-015-4380-0.

Udoh, J., Ekanem, E., 2011. GIS based risk assessment of oil spill in the coastal areas of Akwa Ibom State, Nigeria. African J. Environ. Sci 5, 205–211.

UNEP, 2008. Study of Maritime Traffic Flows in the Mediterranean Sea. EURO-MEDITERRANEAN Partnersh. 40, available at http://www.rempec.org, accessed on 22/5/205.

UNEP, 2010. Sea turtles in the Mediterranean : Distribution, threats and conservation. IUCN-SSC Mar. Turtel Spec. Gr. 113–134.

UNEP, 2011. Satellite tracking of marine turtles in the Mediterranean. Current knowledge and conservation implications. Plan, Mediterr. Action 17–20.

UNEP/MAP, 2012. State of the Mediterranean marine coastal environment, available at http://web.unep.org/unepmap/, accessed on15/10/16.

UNEP-Map (Rac/Spa), 2010. The Mediterranean Sea Biodiversity: state of the ecosystems, pressures, impacts and future priorities. 100.

UNESCO, 1991. Great Man-Made River. Available at http://unesdoc.unesco.org/images/0009/000902/090208eb.pdf, accessed on 27/3/2015

United Nations Convention on the Law of the sea, 2017. Available at, http://www.un.org/depts/los/, accessed on15/1/2017.

USGS, 2014. Available at https://www.usgs.gov/ accessed on 25/12/2014.

Vacchi, M., Montefalcone, M., Schiaffino, C.F., Parravicini, V., Bianchi, C.N., Morri, C., Ferrari, M., 2013. Efficient tools for marine operational forecast and oil spill tracking. Mar. Pollut. Bull. 71, 139–151. doi:10.1016/j.marpolbul.2012.12.009

Vandermeulen, J.H., Ross, C.W., 1995. Oil spill response in freshwater: Assessment of the impact of cleanup as a management tool. J. Environ. Manage. 44, 297–308.

Vinogradov, S., 2013. The Impact of the Deepwater Horizon: The Evolving International Legal Regime for Offshore Accidental Pollution Prevention, Preparedness, and Response. Ocean Dev. Int. Law 44, 335–362.

Walda, W,.2002. Oil Pollution on the Libyan Coast. Unpublished PhD thesis, Southampton University, Southampton, 40 70pp.

Walther III, H.R., 2014. Clean Up Techniques Used for Coastal Oil Spills : an Analysis of Spills Occurring in Santa Barbara , California , Prince William Sound , Alaska , the Sea of Japan , and the Gulf Coast. Masters Project University of San Francisco

Warnock, A.M., Hagen, S.C., Passeri, D.L., 2015. Marine Tar Residues: a Review. Water, Air, Soil Pollut. 226.

Weslawski, J.M., Wiktor, J., Zajaczkowski, M., Futsaeter, G., Moe, K. a., 1997. Vulnerability assessment of Svalbard intertidal zone for oil spills. Estuar. Coast. Shelf Sci. 44, 33–41.

Wind finder, 2015. Available at http://www.windfinder.com/windstatistics/misurata, accessed on 15/9/2015.

WWF, 2005. Marine and coastal resources assessment of the Eastern Region of Libya. Authority, Environ. Gen. 80.

Wynja, V., Demers, A.-M., Laforest, S., Lacelle, M., Pasher, J., Duffe, J., Chaudhary, B., Wang, H., Giles, T., 2015. Mapping Coastal Information across Canada's Northern Regions Based on Low-Altitude Helicopter Videography in Support of Environmental Emergency Preparedness Efforts. J. Coast. Res. 31, 276–290.

Xu, Q., Li, X., Wei, Y., Tang, Z.Y., Cheng, Y.C., Pichel, W.G. 2013. Satellite observations and modelling of oil spill trajectories in the Bohai Sea. Mar. Pollut. Bull. 71, 107-116.

Yanez-Arancibia, A, Day, J.W., Ya, A., 2004. The Gulf of Mexico: towards an integration of coastal management with large marine ecosystem management. Ocean Coast. Manag. 47, 537–563.

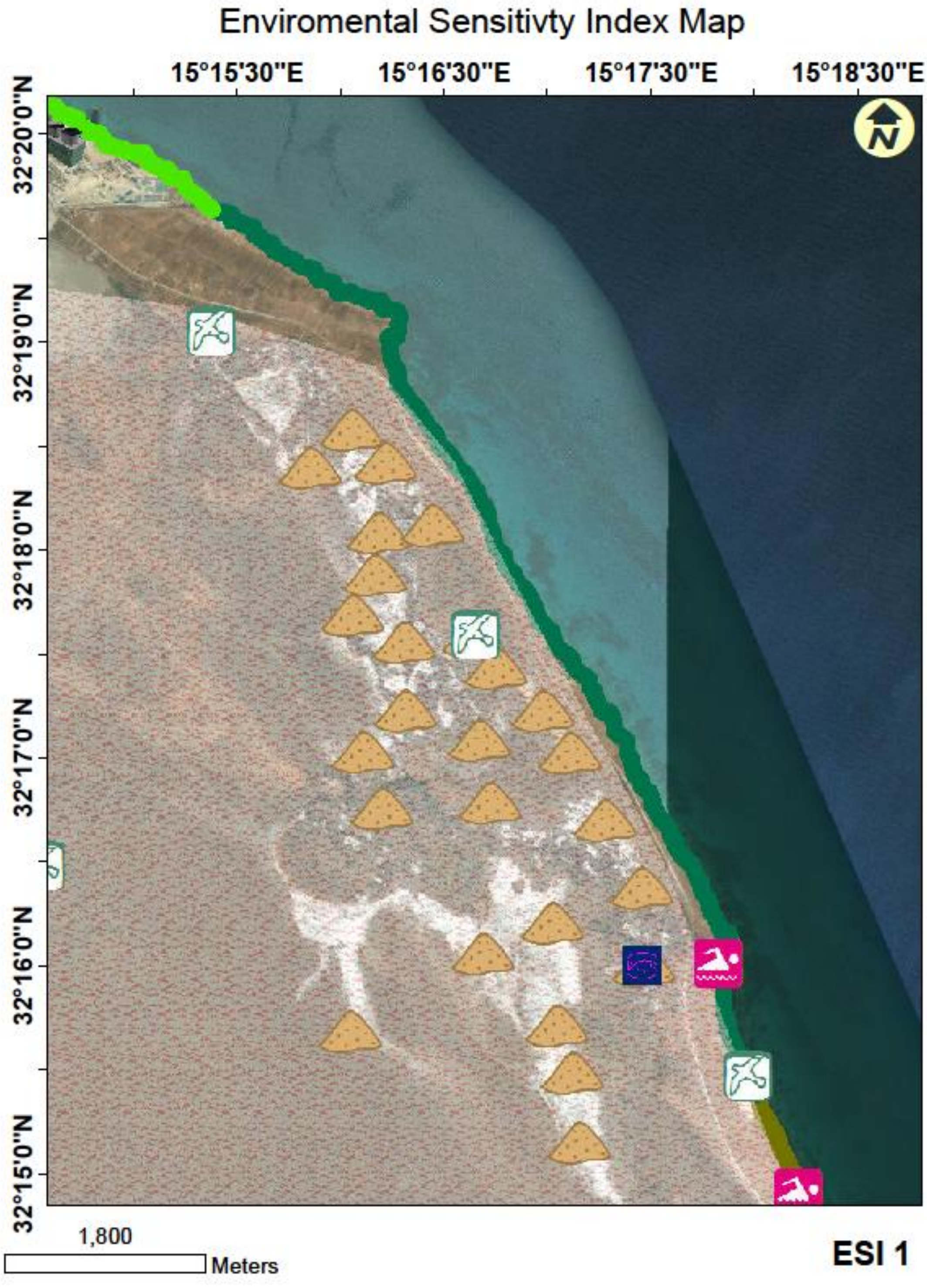
Yoshioka, G., Madelyn C, 2002.Characteristics of Reported Inland and Coastal Oil Spills, https://archive.epa.gov/emergencies/content/fss/web/pdf/carpenterpaper.pdf

Ziadat,F,. Al-Buaishe,. T. Oweis, E.. De Pauw,. H.T. 2011. Selection and Characterization of Integrated Benchmark Research Watersheds in Libya. International Center for Agricultural Research in the Dry Areas, available http://www.icarda.org/wli/pdfs/Pub_SelectionAndCharacterization-Libya.pdf, accessed on 25/6/215.

Appendices

Appendix 1 Misratah coastal sensitivity index maps

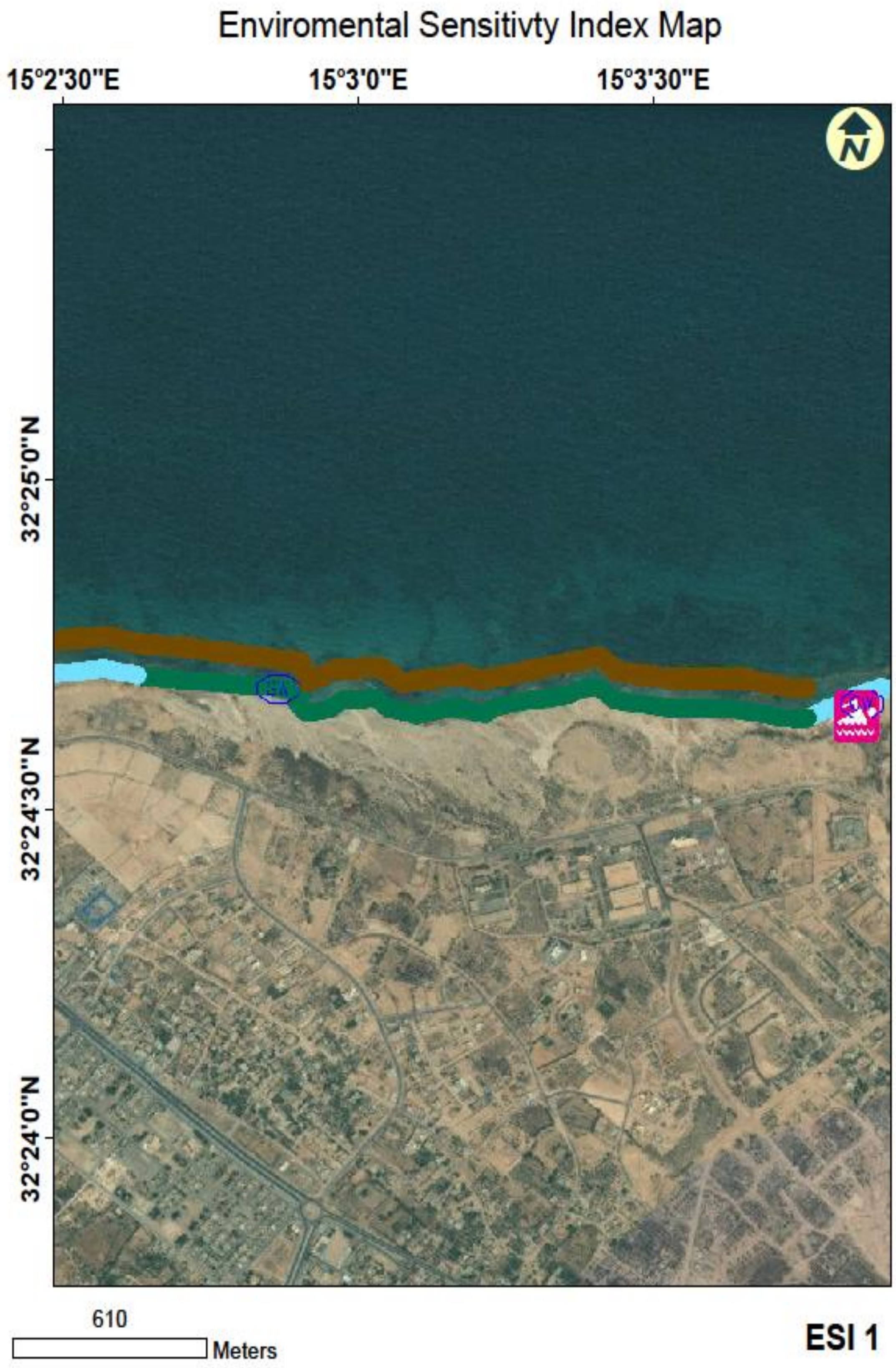
1 - Low Misratah coastal sensitivity index (Gaser-ahmed)



2- Low Misratah coastal sensitivity index (Yedder beach)

3 - Low Misratah coastal sensitivity index (Marbat)

4 - Low Misratah coastal sensitivity index (Aboruaia)

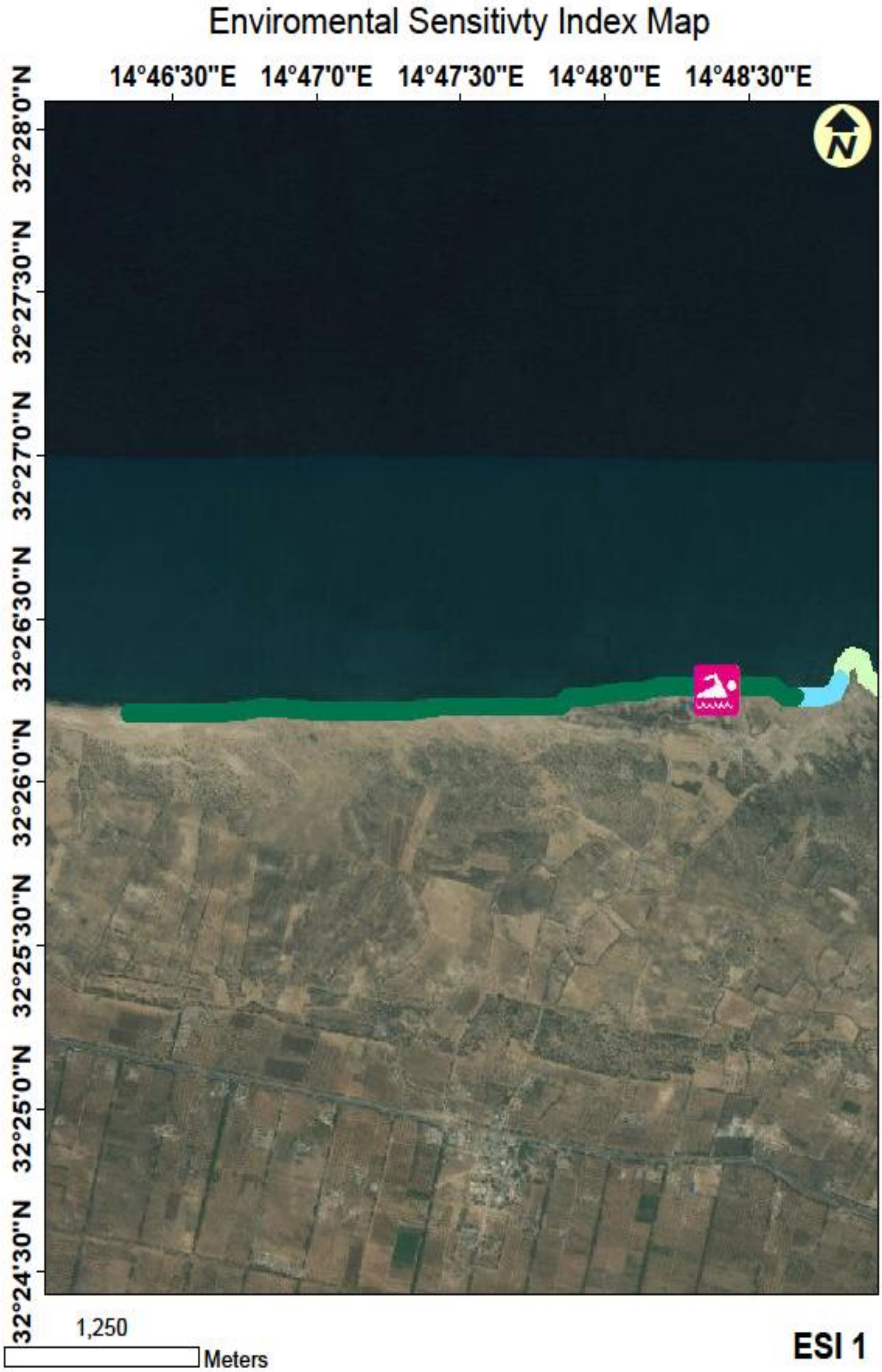


5 - Low Misratah coastal sensitivity index (Abofatma beach)

6 - Low Misratah coastal sensitivity index (Zurek)

7 - Low Misratah coastal sensitivity index (Zurek)

8 - Low Misratah coastal sensitivity index (Dafnia)

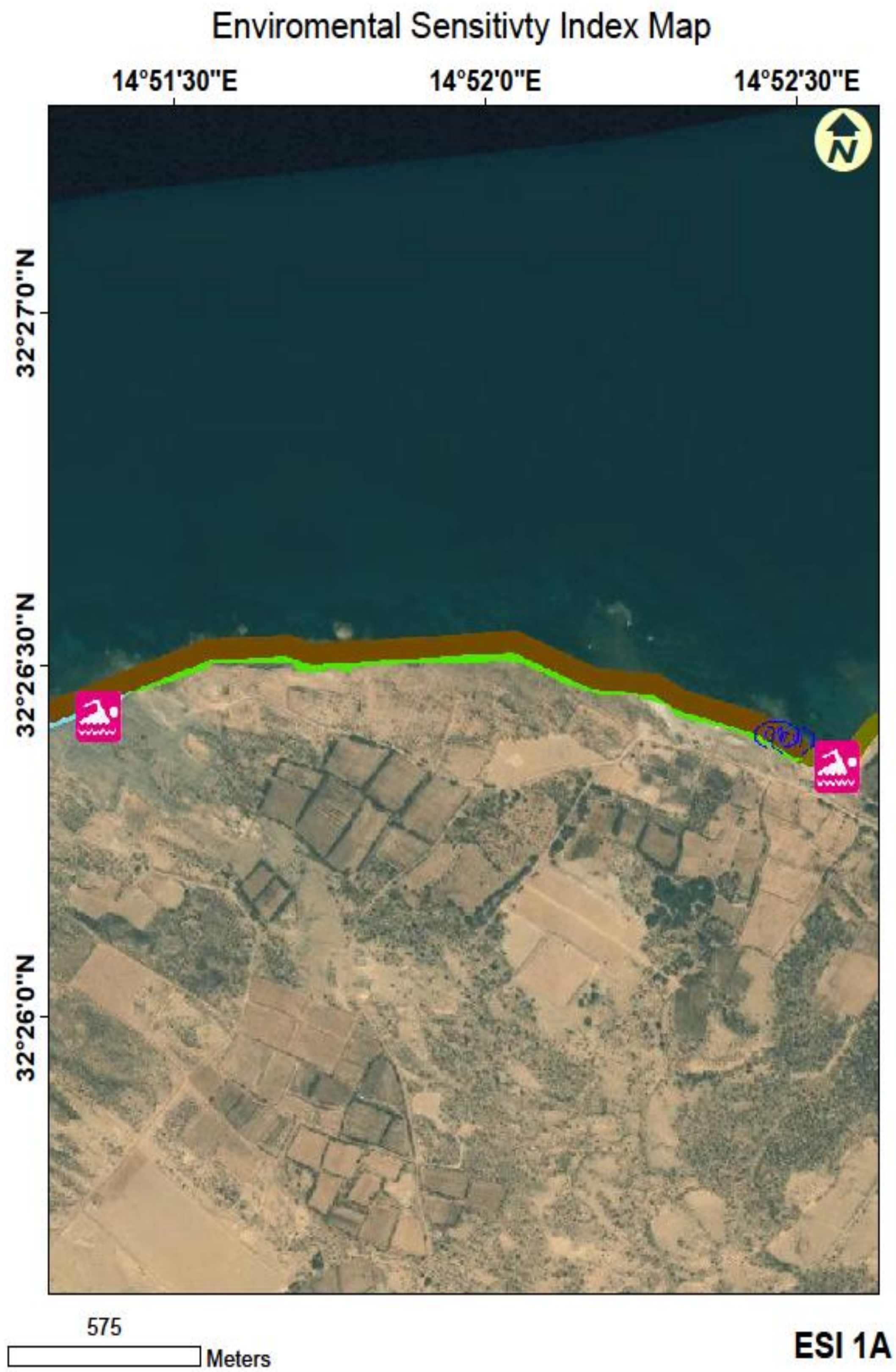


9 - Low Misratah coastal sensitivity index (Gaser-ahmed)

10 - Low Misratah coastal sensitivity index (Gaser-ahmed)

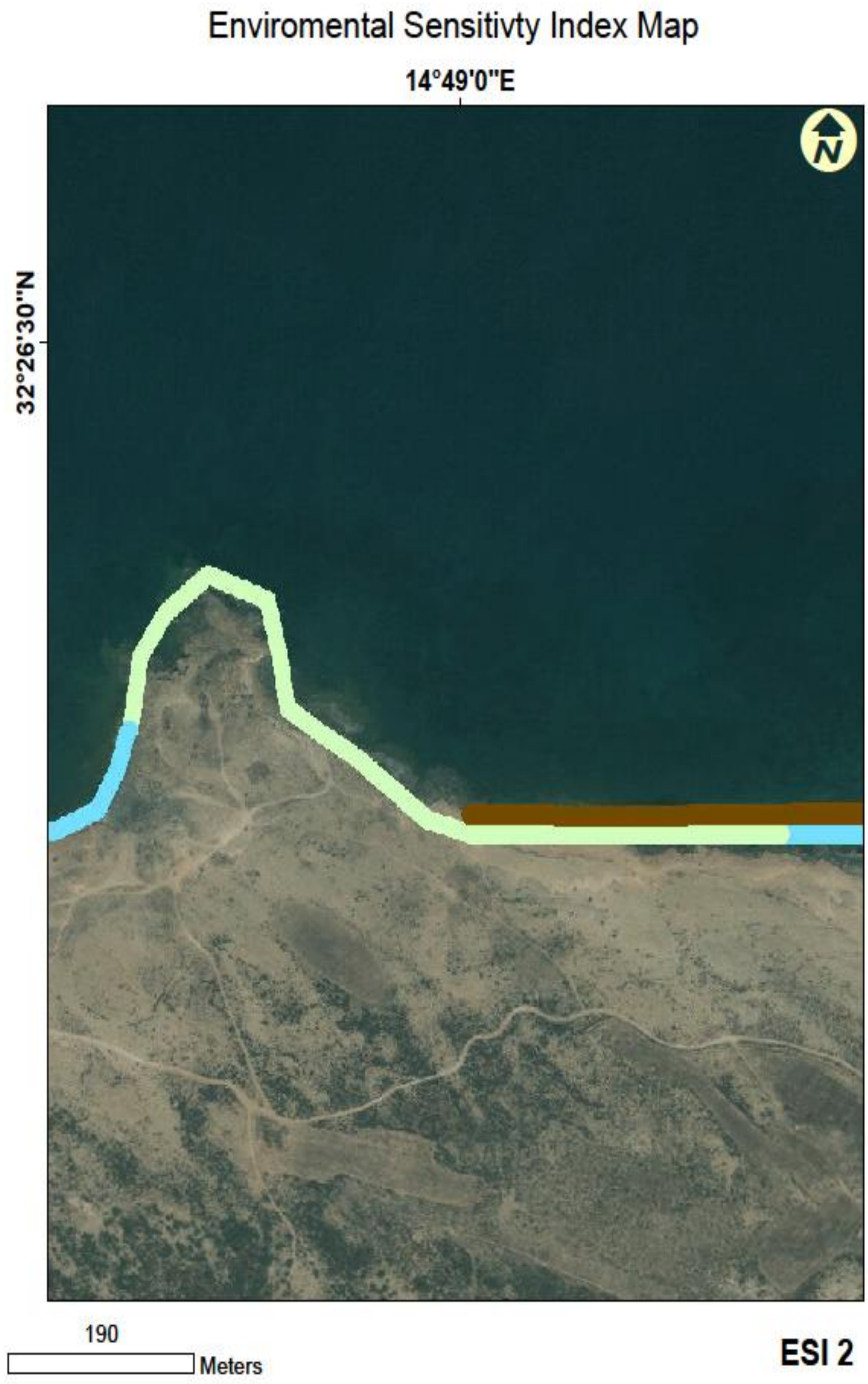
11 - Low Misratah coastal sensitivity index (Zurek)

12 - Low Misratah coastal sensitivity index (Zurek)



13- Low Misratah coastal sensitivity index (Sour-Saud)

14 - Low Misratah coastal sensitivity index (Dafnia)

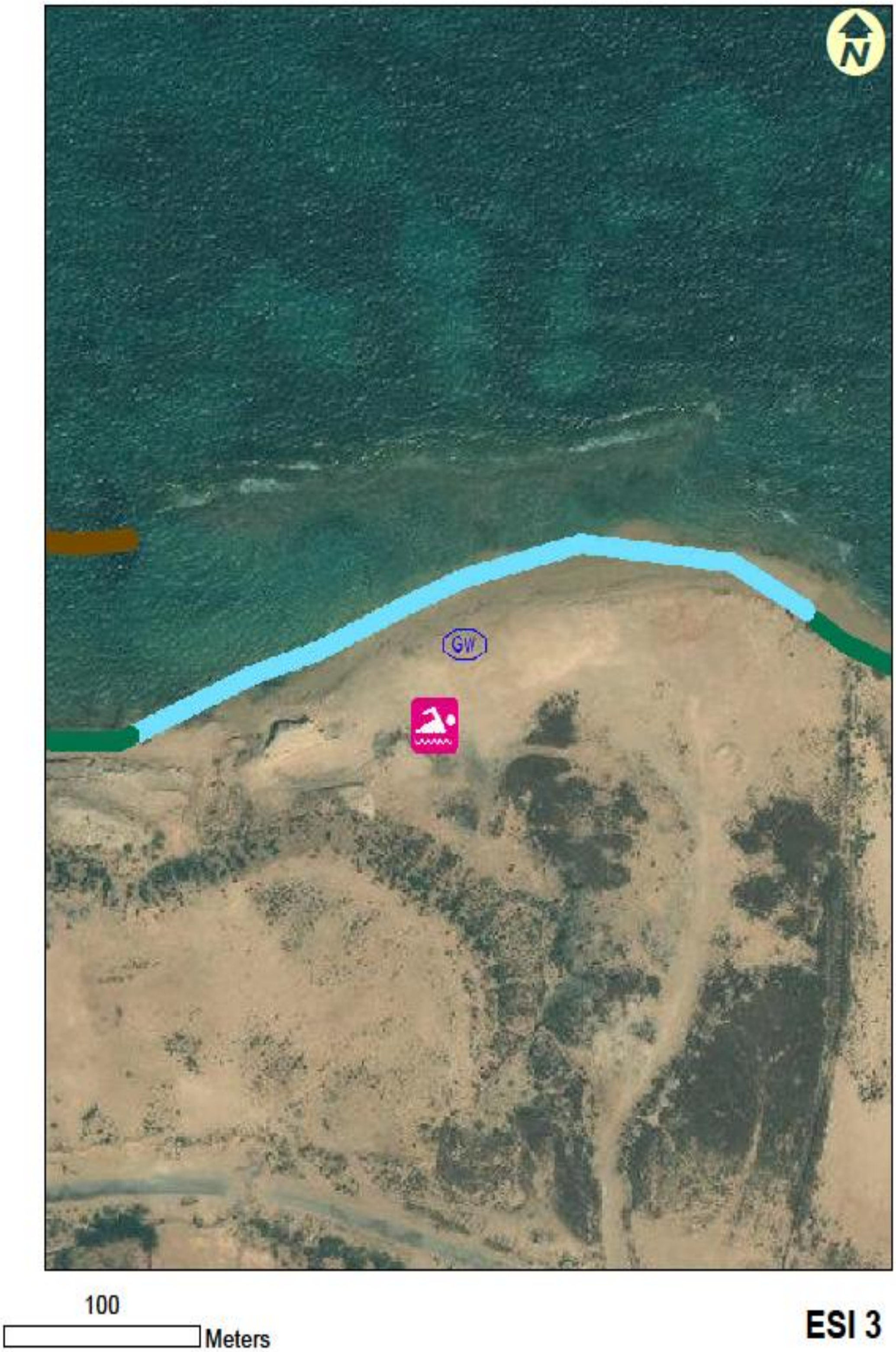


15 – Medium Misratah coastal sensitivity index (Marzuka)

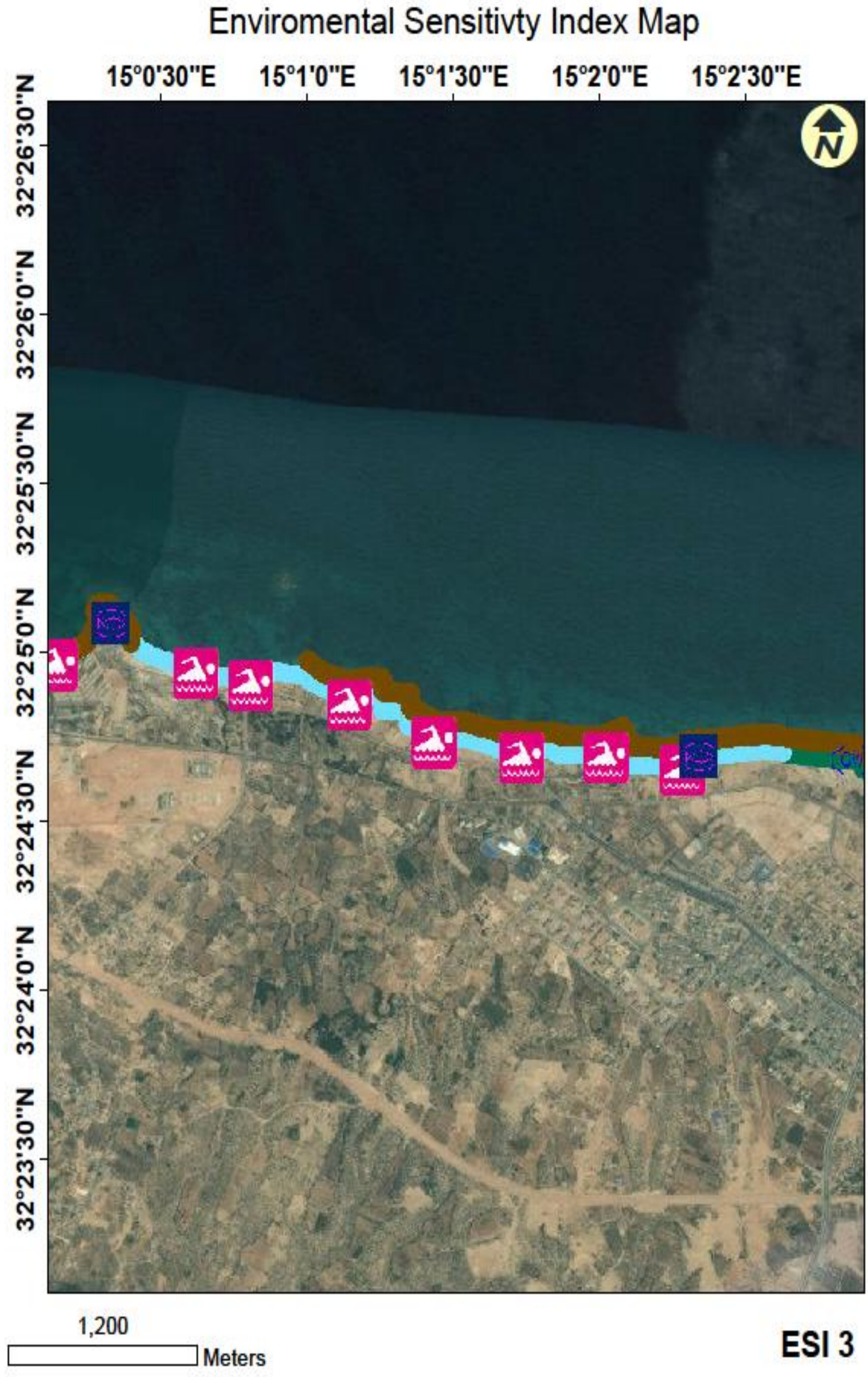
16 – Medium Misratah coastal sensitivity index (Mahaboly)

17 – Medium Misratah coastal sensitivity index (Marbat)

Enviromental Sensitivty Index Map



18 – Medium Misratah coastal sensitivity index (Aljazeera)

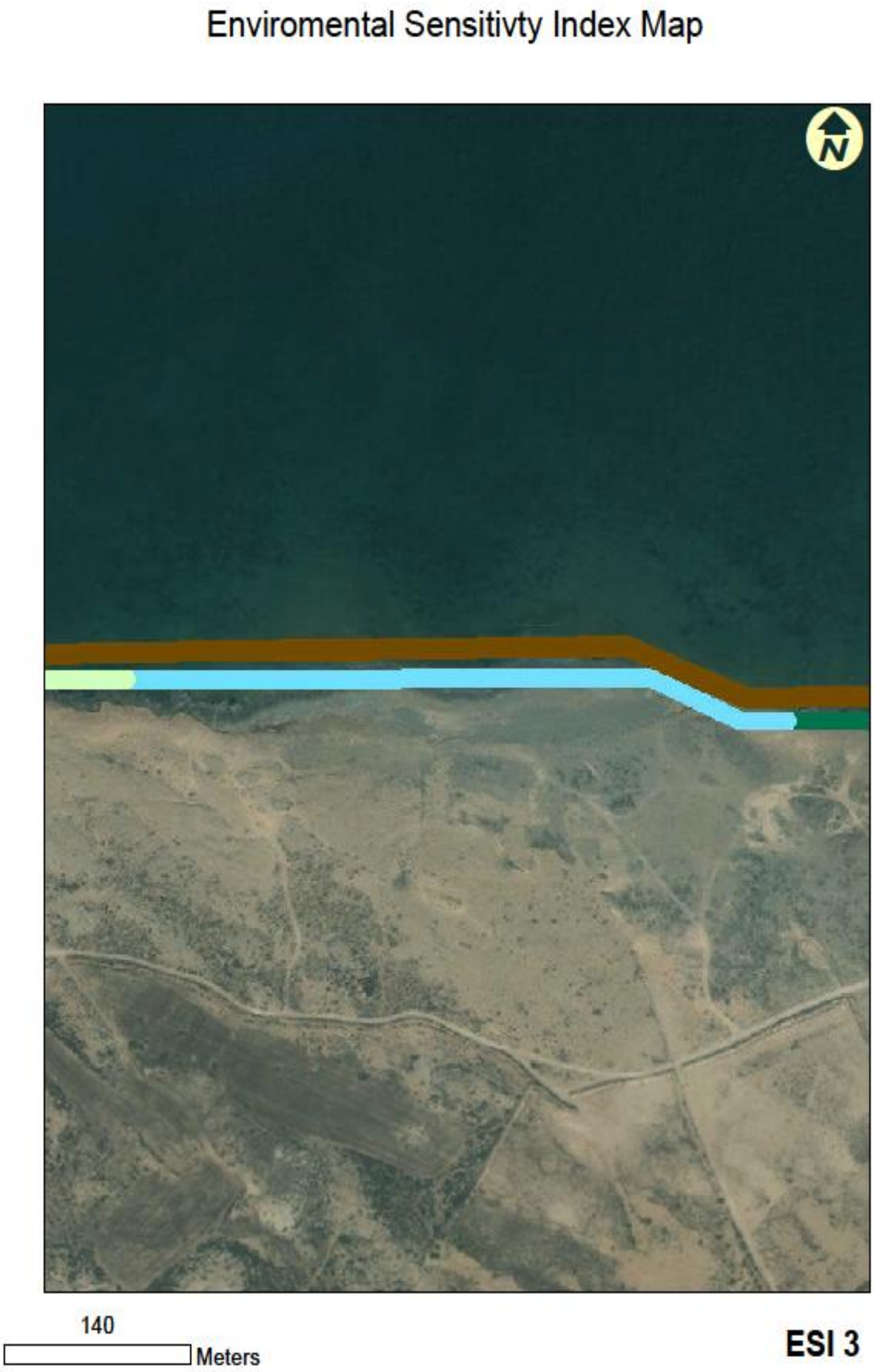


19 – Medium Misratah coastal sensitivity index (Aljazeera)

20 – Medium Misratah coastal sensitivity index (Zurek)

21 – Medium Misratah coastal sensitivity index (Dafnia)

22 – Medium Misratah coastal sensitivity index (Dafnia)

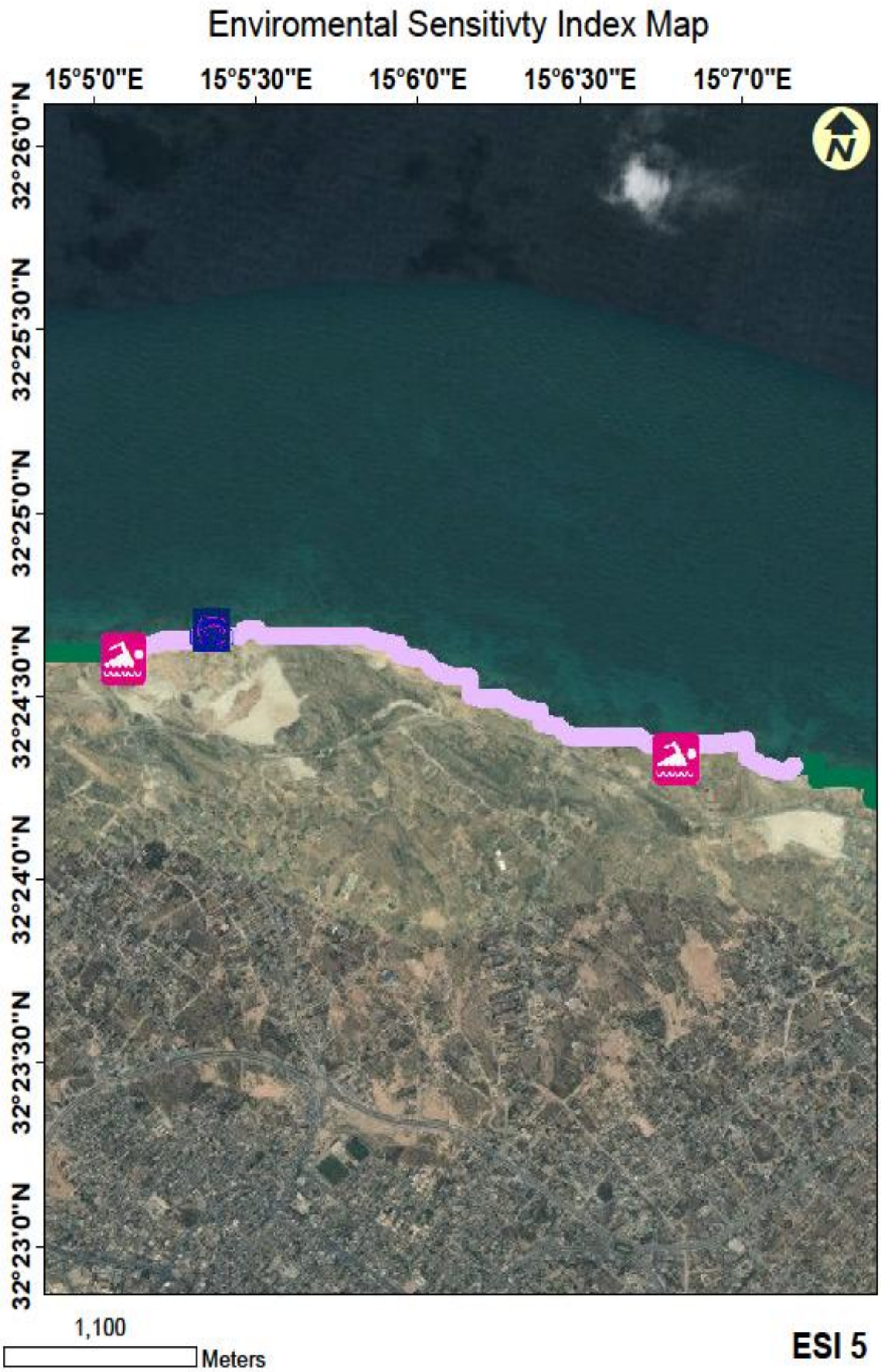


23 – Medium Misratah coastal sensitivity index (Dafnia)

24 – Medium Misratah coastal sensitivity index (Abofatma)

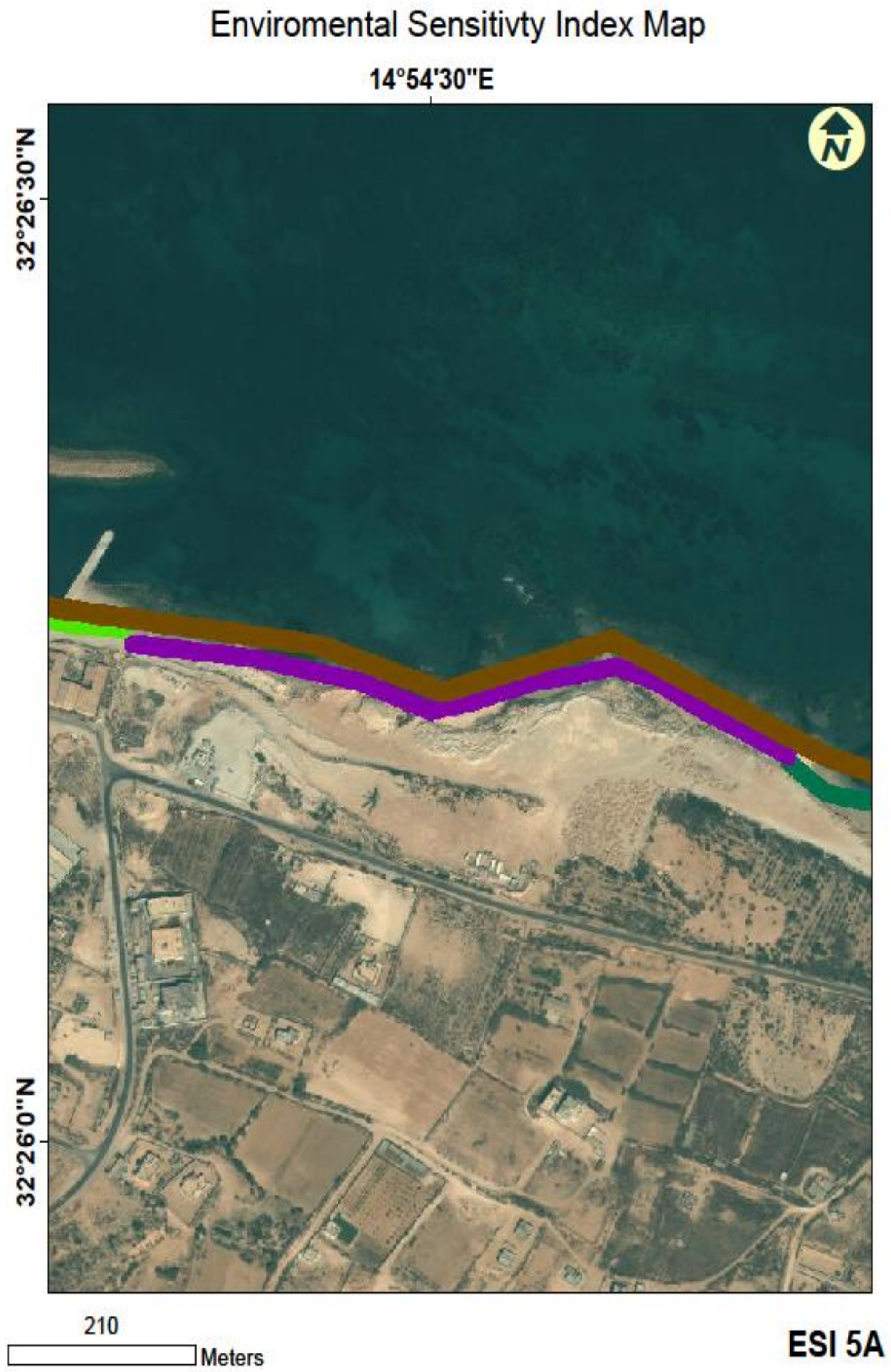
25 – Medium Misratah coastal sensitivity index (Sour-Saud)

26 – Medium Misratah coastal sensitivity index (Yedder beach)



27 – Medium Misratah coastal sensitivity index (Sour-Saud)

28 – Medium Misratah coastal sensitivity index (Zurek)



29– Medium Misratah coastal sensitivity index (Alromia)

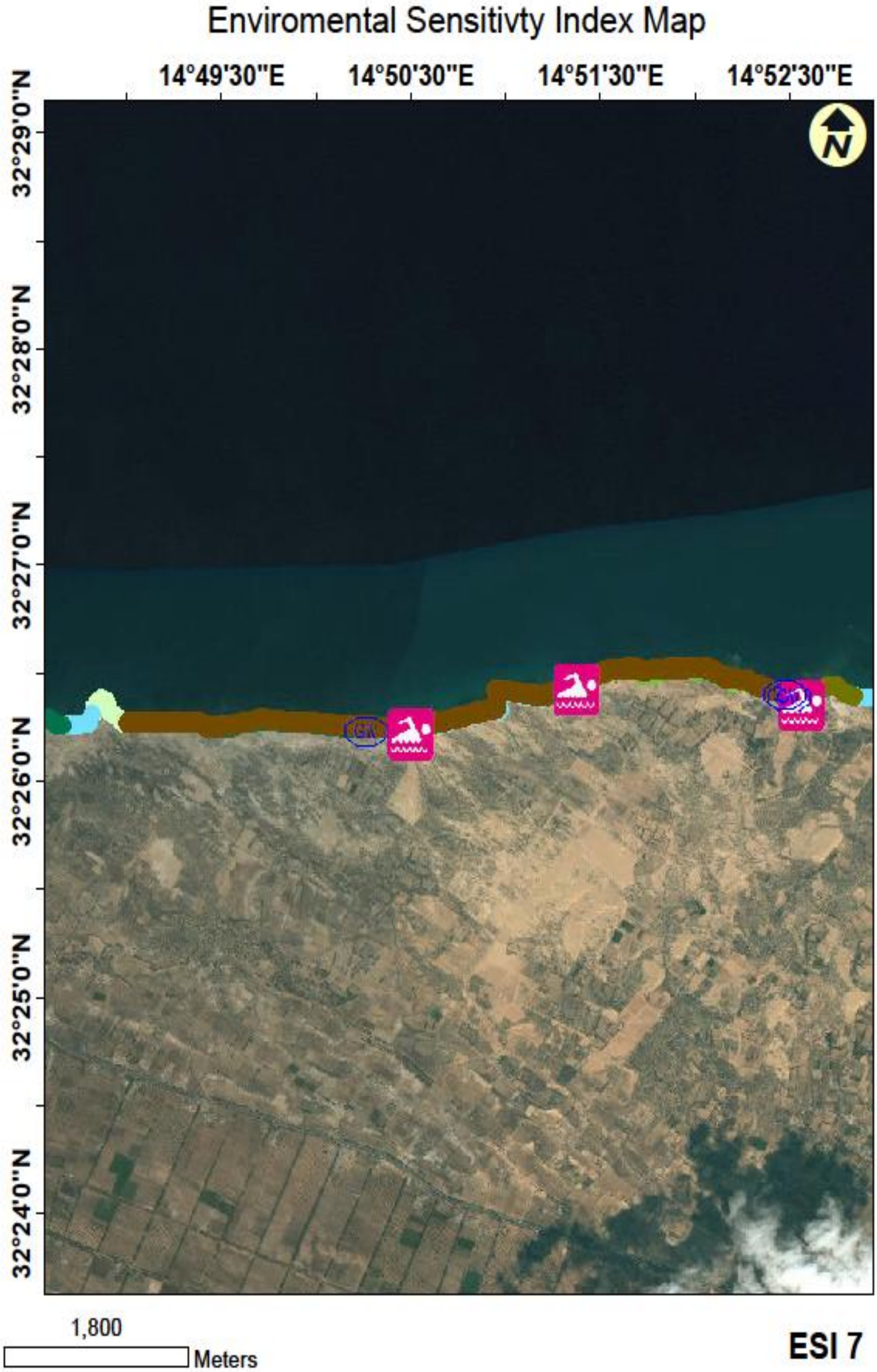
30 – Medium Misratah coastal sensitivity index (Gaser-ahmed)

31 – Medium Misratah coastal sensitivity index (Zurek)

32 – Medium Misratah coastal sensitivity index (Gaser-ahmed)

33 – High Misratah coastal sensitivity index (Aljazeera)

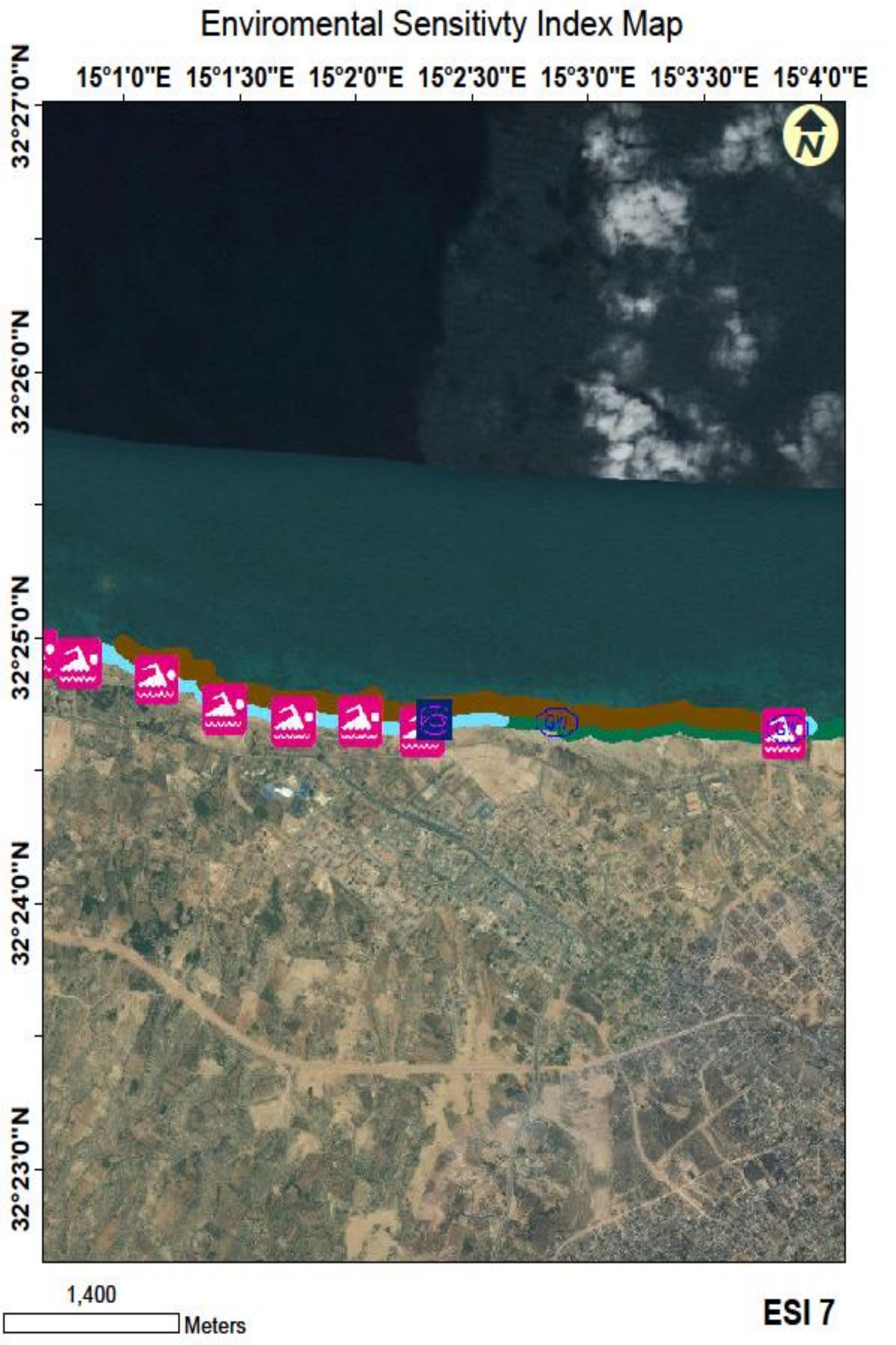
34 – High Misratah coastal sensitivity index (Dafnia)



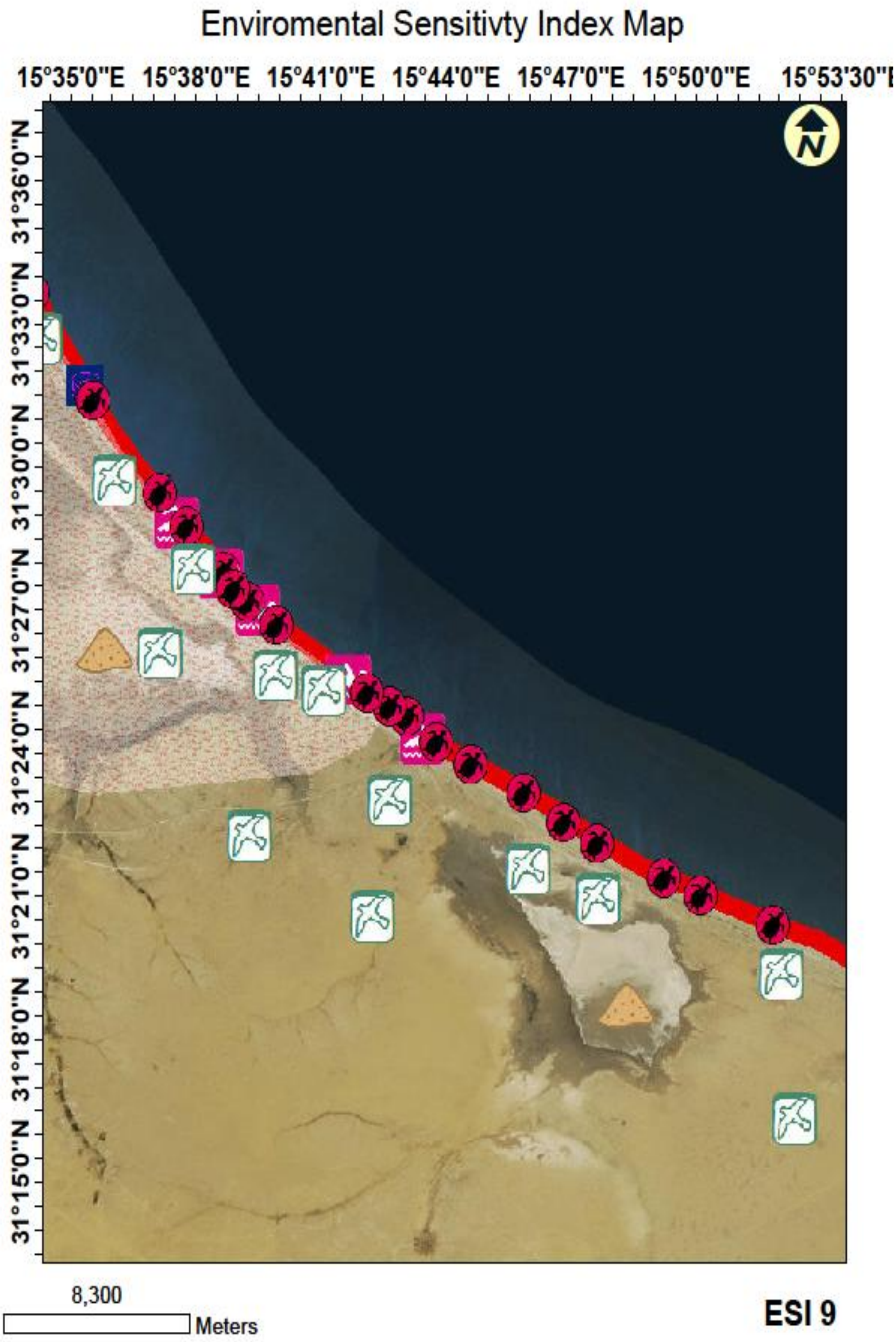
35 – High Misratah coastal sensitivity index (Zurek)

36– High Misratah coastal sensitivity index (Aljazeera)

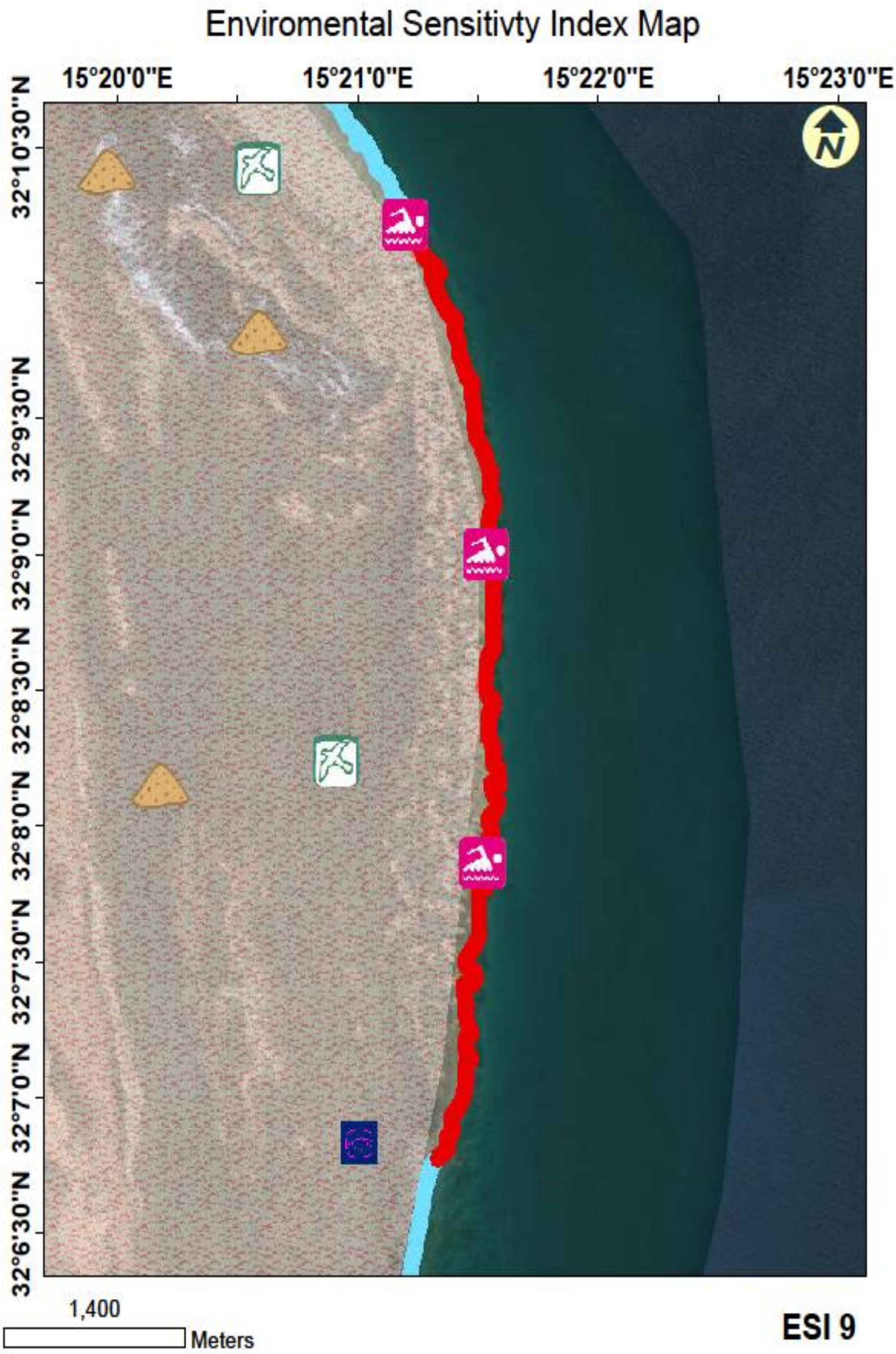
37 – High Misratah coastal sensitivity index (Aljazeera)



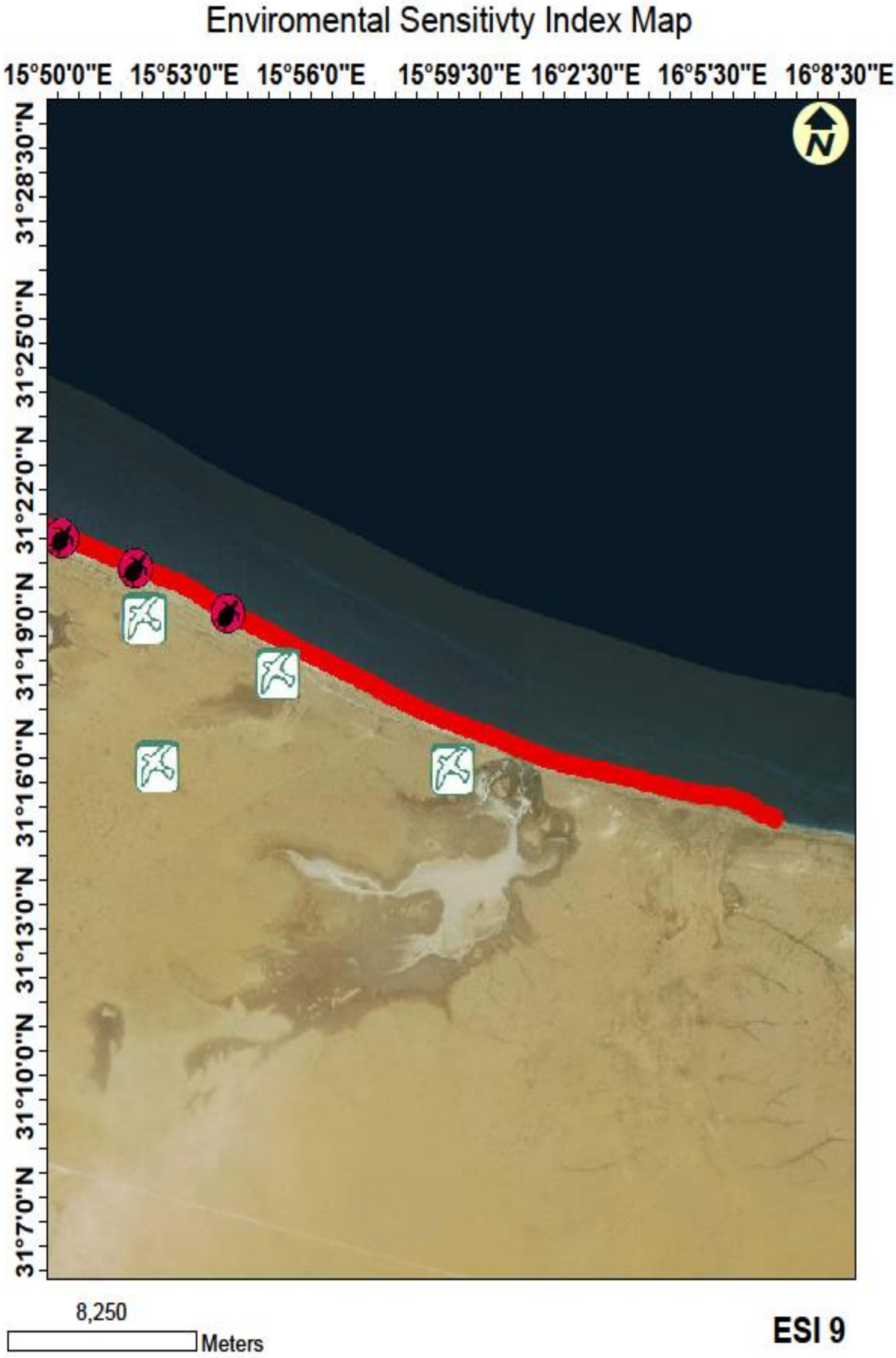
38 – Very high Misratah coastal sensitivity index (Buerat)



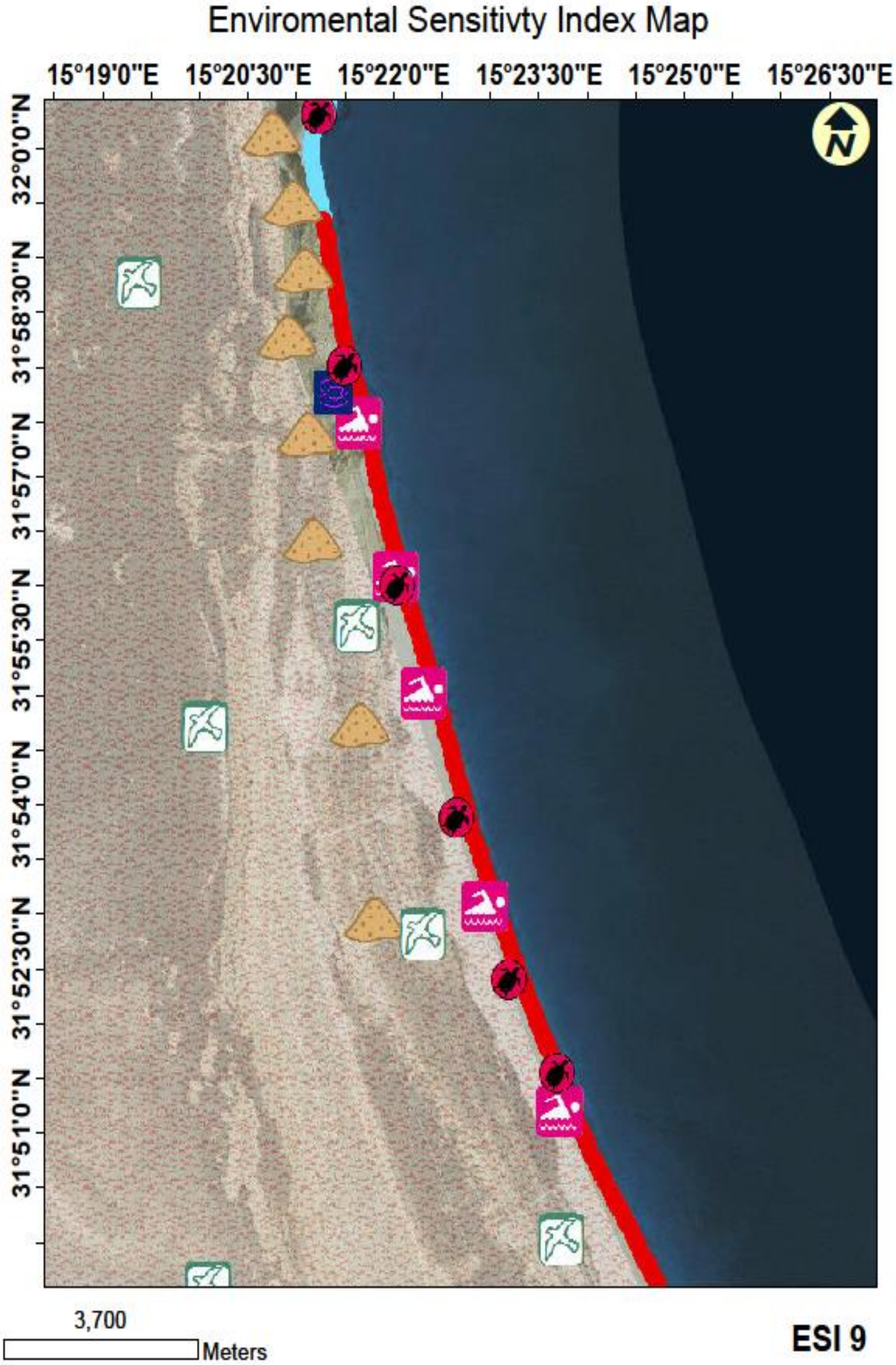
39 – Very high Misratah coastal sensitivity index (Alkouda)



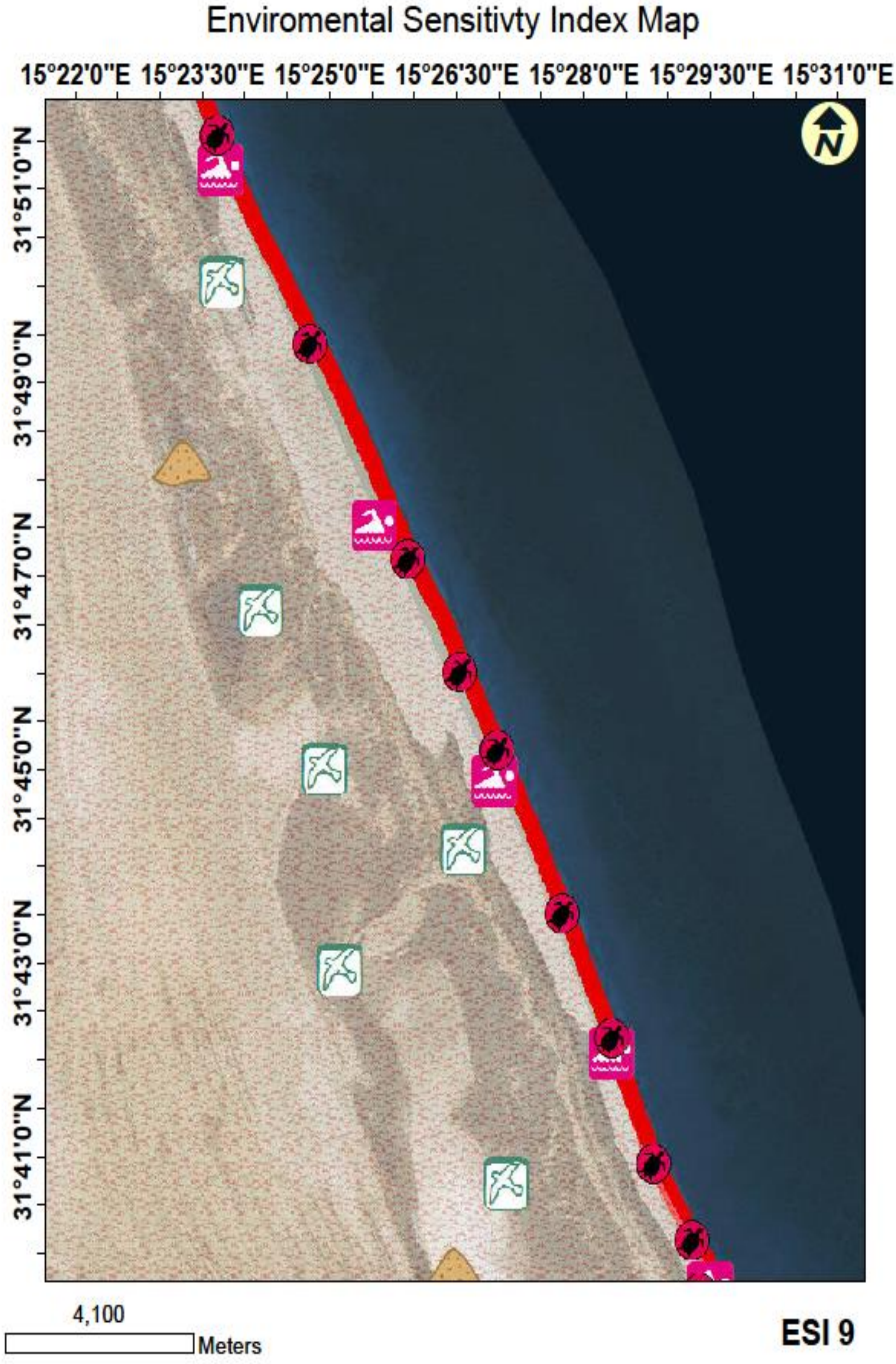
40 – Very high Misratah coastal sensitivity index (Almajaran)



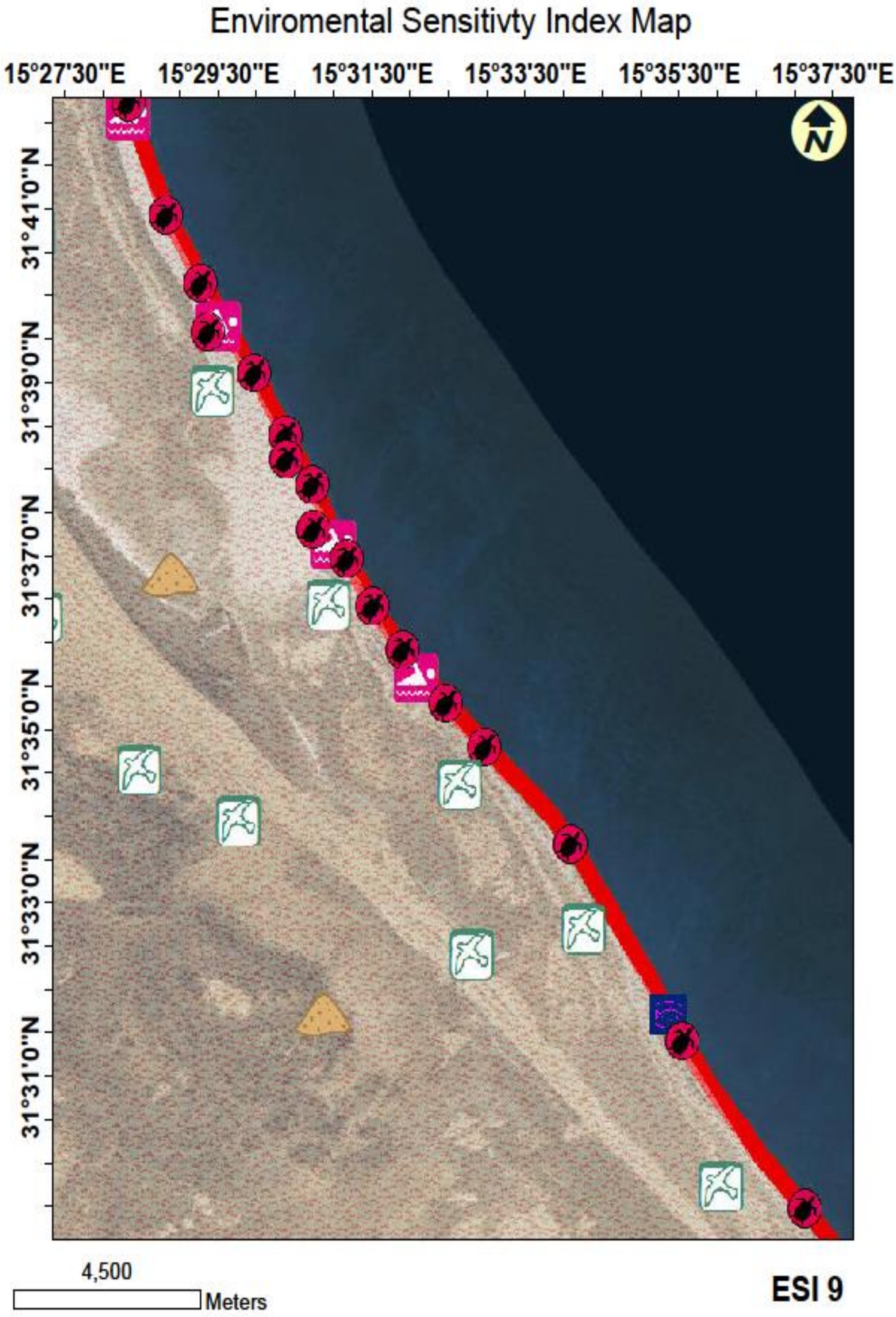
41 – Very high Misratah coastal sensitivity index (Marzouga)



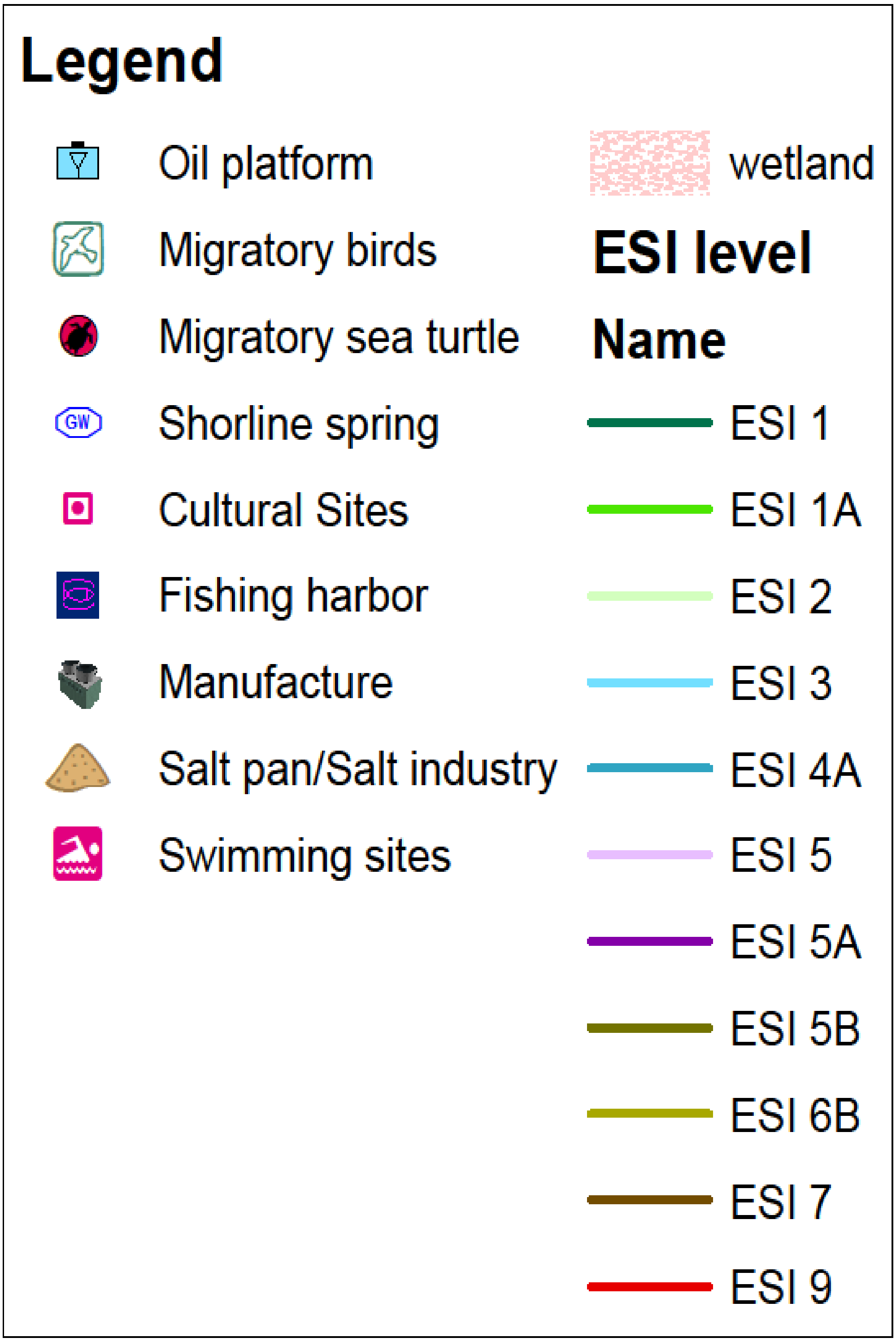
42– Very high Misratah coastal sensitivity index (Mahaboly)



43– Very high Misratah coastal sensitivity index (Alroumia)



Colour code of the Environmental Sensitivity Index with symbols for the mapping of sensitive socio-economic and biological resources



Appendix 2 ESI Index and oil risk index summary of shoreline

Table 1 Summary of shoreline of Misratah coast by ESI level and oil risk values (North shoreline).

NO	Habitats	ESI category	Length /km	Location	Oil risk level
1	Exposed rocky shore	ESI 1	4.79	Yedder beach	High risk
2	Exposed rocky shore	ESI 1	1.87	Aboruaia	High risk
3	Exposed rocky shore	ESI 1	1.92	Abofatma beach	High risk
4	Exposed rocky shore	ESI 1	2.19	Zurek	Medium risk
5	Exposed rocky shore	ESI 1	1.02	Zurek	Medium risk
6	Exposed rocky shore	ESI 1	1.28	Dafnia	Medium risk
7	Exposed rocky shore	ESI 1	3.75	Dafnia	Medium risk
8	Exposed man made structure	ESI 1A	9.20	Gaser-ahmed	High risk
9	Exposed man made structure	ESI 1A	8.28	Gaser-ahmed	High risk
10	Exposed man made structure	ESI 1A	0.45	Zurek	Medium risk
11	Exposed man made structure	ESI 1A	1.79	Sour-Saud	High risk
12	Exposed wave cut platform in bedrock	ESI 2	4.54	Sour Saud	High risk
13	Exposed wave cut	ESI 2	4.79	Dafnia	Medium

	platform in bedrock				risk
14	Fine to medium sandy beaches with mostly moderate sloping	ESI 3	0.32	Marzuka	High risk
15	Fine to medium sandy beaches with mostly moderate sloping	ESI 3	3.99	Mahaboly	Medium risk
16	Fine to medium sandy beaches with mostly moderate sloping	ESI 3	1.27	Aljazeera	Medium risk
17	Fine to medium sandy beaches with mostly moderate sloping	ESI 3	2.45	Zurek	Medium risk
18	Fine to medium sandy beaches with mostly moderate sloping	ESI 3	2.13	Dafnia	Medium risk
19	Fine to medium sandy beaches with mostly moderate sloping	ESI 3	0.43	Zurek	Medium risk
20	Fine to medium sandy beaches with mostly moderate sloping	ESI 3	0.30	Dafnia	Medium risk
21	Shorelines with coarse sand and mostly sloping	ESI 4A	3.60	Zurek	Medium risk
22	Shorelines with coarse sand and mostly sloping	ESI 4A	1.21	Sour Saud	High risk
23	Mixed sand and gravel beaches(cliff shore)	ESI 5	3.73	Jannat	High risk
24	Mixed sand and gravel beaches(cliff shore)	ESI 5	1.72	Zurek	Medium risk
25	Irregular protrusions of	ESI 5A	0.67	Zurek	Medium

	rocks through sand				risk
26	Boulder shore	ESI 5B	1.68	Gaser-ahmed	High risk
27	Boulder shore	ESI 5B	0.64	Zurek	Medium risk
28	Boulder shore	ESI 5B	3.16	Gaser-ahmed	High risk
29	Riprap beach	ESI 6B	0.40	Aljazeera	High risk
30	Exposed tidal flat	ESI 7	5.98	Dafnia	Medium risk
31	Exposed tidal flat	ESI 7	3.67	Zurek	Medium risk
32	Exposed tidal flat	ESI 7	0.69	Aljazeera	High risk
33	Exposed tidal flat	ESI 7	4.77	Dafnia	Medium risk

Table 2 Summary of shoreline of Misratah coast by ESI level and oil risk values (East shoreline)

NO	Habitats	ESI category	Length /km	Location	Oil risk level
1	Exposed rocky shore	ESI 1	9.79	Gaser-ahmed	High risk
2	Fine to medium sandy beaches with mostly moderate sloping	ESI 3	14.22	Dafnia	Medium risk
3	Fine to medium sandy beaches with mostly moderate sloping	ESI 3	6.44	Dafnia	Medium risk
4	Boulder shore	ESI 5B	4.81	Albonta	Low risk
5	Vegetated low bank	ESI 9	33.35	Buerat	Medium risk
6	Vegetated low bank	ESI 9	6.91	Alromia	Low risk
7	Vegetated low bank	ESI 9	27.92	Buerat	Medium risk
8	Vegetated low bank	ESI 9	16.68	Marzouga	Low risk
9	Vegetated low bank	ESI 9	19.75	Alkouda	Low risk
10	Vegetated low bank	ESI 9	23.52	Alkouda	Low risk

Appendix 3 Input field data to ArcMap as points in excel file

Table 1 Cooling water location

Colling water	Longitude	Luddite
H1	15°13'59.76	32°20'37.40
H2	15°15'10.60	32°19'48.32
H3	15°13'54.06	32°20'42.01
H4	15°14'43.64	32°20'0.79

Table 2 Sewage pipes location

Number	Longitude	Luddite
P1	15° 2'45.16	32°24'40.89
P2	15° 4'59.64	32°24'36.22
P3	15°10'51.27	32°23'16.79
P4	15°13'47.00	32°20'47.96

Table 3 Iron factory location

Number	Longitude	Luddite
R1	15°13'36.97	32°20'34.97

Table 4 Sea ports location

Number	Longitude	Luddite
O1	15°12'59.97"E	32°21'33.78
O2	15°14'19.76	32°20'27.33

Table 5 Oil storages and export location

Number	Longitude	Luddite
O1	15°12'44.61	32°22'8.45

Table 6 Power plant location

Number	Longitude	Luddite
G1	15°14'40.68	32°19'59.56

Table 7 Fishing ports location

Number	Longitude	Luddite
F1	15°21'18.70	32° 0'23.30
F2	15°12'54.93	32°22'23.92

F 3	15° 2'20.39	32°24'42.56
F 4	15° 0'19.87	32°25'3.81
F5	14°54'6.58	32°26'15.51

Table 8 Tourist area location

Number	Longitude	Luddite
T1	14°55'5.70	32°26'4.39
T2	15° 0'10.07	32°24'55.74
T3	15° 0'53.46	32°24'54.20
T4	15° 1'3.01	32°24'52.32
T5	15° 1'6.72	32°24'50.74
T6	15° 1'19.60	32°24'45.77
T7	15° 1'33.91	32°24'42.51
T8	15° 1'51.29	32°24'39.90
T9	15° 6'56.59	32°24'17.62
T10	15°14'29.54	32°20'9.39

Table 9 Tar ball geographic distribution

NO	Coastal area	Geographic location		Coastal feature	Desistance from the sea line/M	Shoreline type
1	Dafnia	14°44'12.09"E	32°26'34.90"N	Open sea	5	Exposed rocky shore
2	Dafnia	14°46'46.38"E	32°26'13.69"N	Open sea	15	Rocky shore
3	Dafnia	14°47'9.09"E	32°26'12.75"N	Open sea	10	Rocky shore
4	Ras Alhensher	14°47'29.77"E	32°26'13.57"N	Semi-closed beach	20	Sandy beach
5	Dafnia	14°48'48.51"E	32°26'17.34"N	Open sea	5	Rocky shore
6	Dafnia	14°49'12.67"E	32°26'15.05"N	Open sea	20	Mixed sandy and rocky shore
7	Borwaia	14°50'34.98"E	32°26'14.29"N	Semi-closed beach	17	Sandy beach
8	Zurek	14°50'57.70"E	32°26'20.89"N	Small bay	15	Sandy beach
9	Zurek	14°51'12.56"E	32°26'23.38"N	Semi-closed beach	3	Sandy beach
10	Zurek	14°52'36.51"E	32°26'23.59"N	Semi-closed beach	5	Rocky shore
11	Zurek	14°52'58.42"E	32°26'23.13"N	Open sea	7	Sandy beach
12	Zurek	14°53'13.86"E	32°26'22.53"N	Rocky platform	10	Sandy beach
13	Zurek	14°53'30.33"E	32°26'22.71"N	Wave cut platform	12	Grovel beach
14	Abo fatma	14°54'7.64"E	32°26'17.45"N	Open sea	5	Rocky shore
15	Abo fatma	14°54'35.28"E	32°26'14.90"N	Headland	8	Sandy beach
16	Sawawa	14°55'48.86"E	32°25'56.62"N	Open sea	3	Sandy beach
17	Sawawa	14°56'50.19"E	32°25'43.00"N	Open sea	6	Sandy beach
18	Edzira	15° 0'16.79"E	32°25'4.54"N	Semi-closed beach	1	Man-made wall
19	Edzira	15° 2'20.51"E	32°24'42.87"N	Semi-closed beach	1	Man-made wall
20	Altoba	15° 2'35.24"E	32°24'42.40"N	Open sea	6	Wave cut platform
21	Altoba	15° 2'58.68"E	32°24'40.44"N	Open sea	7	Sandy beach
22	Aljazeera	15° 5'21.47"E	32°24'40.66"N	Open sea	2	Sandy beach
23	Jannat	15°10'27.12"E	32°23'20.51"N	Headland	17	Rocky shore
24	Zaroog	15°11'37.40"E	32°23'0.31"N	Open sea	7	Sandy beach
25	Almelayta	15°12'2.99"E	32°22'52.93"N	Open sea	17	Sandy beach
26	Almelayta	15°12'21.94"E	32°22'44.82"N	Open sea	15	Sandy beach
27	Gaser-ahmed	15°12'40.13"E	32°22'33.36"N	Open sea	20	Grovel beach
28	Gaser-ahmed	15°13'0.00"E	32°22'22.51"N	Semi-closed beach	12	Grovel beach
29	Gaser-ahmed	15°13'3.55"E	32°22'19.01"N	Harbour	1	Man-made structure
30	Gaser-ahmed (Eastern coast)	15°13'25.65"E	32°21'10.85"N	Harbour	10	Rocky shore
31	Gaser-ahmed (Eastern coast)	15°13'39.83"E	32°20'58.13"N	Semi-closed beach	2	Rocky shore
32	Gaser-ahmed (Eastern coast)	15°13'50.87"E	32°20'44.91"N	Semi-closed beach	1	Rocky shore
33	Gaser-ahmed (Eastern coast)	15°14'22.01"E	32°20'33.91"N	Semi-closed beach	2	Man-made structure
34	Gaser-ahmed (Eastern coast)	15°14'41.54"E	32°20'5.16"N	Harbour	7	Rocky shore
35	Gaser-ahmed (Eastern coast)	15°15'56.94"E	32°19'17.09"N	Semi-closed beach	5	Rocky shore
36	Gaser-ahmed (Eastern coast)	15°17'52.77"E	32°16'3.64"N	Open sea	8	Wave cut platform
37	Alromia (Eastern coast)	15°21'24.64"E	32° 6'46.74"N	Headland	2	Wave cut platform
38	Mahaboly (Eastern coast)	15°21'28.13"E	32° 7'9.02"N	Headland	3	Wave cut platform
39	Mahaboly (Eastern coast)	15°21'33.66"E	32° 7'57.91"N	Headland	2	Wave cut platform
40	Mahaboly (Eastern coast)	15°21'34.07"E	32° 8'39.35"N	Headland	1	Wave cut platform
41	Mahaboly (Eastern coast)	15°21'34.69"E	32° 9'10.85"N	Anchorage	1	Man-made structure

Appendix 4 Winds speed and direction data in GNOME simulations

Table 1 Koums winds coast (winter): at latitude and longitude location 32°37'47.25"N 14°20'1.20"E

day	month	direction	Direction/degree	Speed/knots
16th	January	WNW	300	12
17th	January	WNW	295	12
18th	January	WNW	290	12
19th	January	W	273	13
20th	January	N	354	14
21st	January	NW	312	15
22nd	January	NW	310	16
23rd	January	WNW	303	16
24th	January	W	269	16
25th	January	W	271	15
26th	January	W	275	13
27th	January	WNW	296	13
28th	January	NW	322	13
29th	January	NW	307	13
30th	January	NW	314	13
31st	January	NW	323	13
1st	February	NW	303	13
2nd	February	NW	316	14
3rd	February	NW	308	14
4th	February	NW	315	13
5th	February	NW	316	11
6th	February	WNW	297	11
7th	February	NW	313	12
8th	February	NW	310	13
9th	February	NW	325	14
10th	February	NW	310	15
11th	February	NW	306	17
12th	February	NW	306	16
13th	February	NW	317	15
14th	February	NW	309	13
15th	February	NW	312	12

Appendix 4 Winds speed and direction data in GNOME simulations

Table 2 Koums winds coast (summer) at latitude and longitude location 32°37'47.25"N 14°20'1.20"E

Day	month	direction	Direction/degree	Speed/knots
16th	July	NNE	27	8
17th	July	NE	36	9
18th	July	NE	39	8
19th	July	NNE	23	8
20th	July	N	355	8
21st	July	N	352	8
22nd	July	NNW	347	7
23rd	July	N	349	8
24th	July	N	5	7
25th	July	N	8	8
26th	July	NNE	11	9
27th	July	NNE	11	9
28th	July	N	352	9
29th	July	NNW	343	8
30th	July	NNW	345	9
31st	July	N	350	9
1st	August	N	355	9
2nd	August	N	3	8
3rd	August	NNE	18	7
4th	August	NNE	32	8
5th	August	NE	34	8
6th	August	NNE	19	9
7th	August	N	6	9
8th	August	N	2	8
9th	August	NNE	11	7
10th	August	NNE	24	7
11th	August	NNE	26	7
12th	August	NNE	21	9
13th	August	NE	34	8
14th	August	NNE	30	8
15th	August	NNE	22	8

Table 3 Tripoli winds on coast (winter) at latitude and longitude location 32°47'35.46 "N 12°40'49.33 "E

Day	month	direction	Direction/degree	Speed/knots
16th	January	WNW	303	11
17th	January	NW	306	12
18th	January	W	269	11
19th	January	WNW	287	12
20th	January	NW	311	13
21st	January	NW	313	14
22nd	January	NW	310	15
23rd	January	WNW	283	15
24th	January	W	274	15
25th	January	W	274	15
26th	January	WNW	301	14
27th	January	WNW	285	13
28th	January	WNW	303	13
29th	January	NW	309	13
30th	January	NW	313	12
31st	January	NW	314	12
1st	February	NW	308	12
2nd	February	NW	316	14
3rd	February	NW	307	13
4th	February	NW	311	12
5th	February	NW	319	11
6th	February	WNW	286	11
7th	February	WNW	290	12
8th	February	NW	324	13
9th	February	NNW	327	14
10th	February	NW	307	15
11th	February	NW	314	15
12th	February	NW	317	14
13th	February	NW	322	13
14th	February	NW	313	12
15th	February	NW	309	12

Appendix 4 Winds speed and direction data in GNOME simulations

Table 4 Tripoli winds on coast (summer) at latitude and longitude location 32°47'35.46 "N 2° 40'49.33 "E

data	Month	direction	Direction/degree	Speed/knots
16th	July	NE	43	10
17th	July	NE	39	10
18th	July	NE	44	9
19th	July	NE	38	10
20th	July	NNE	16	10
21st	July	N	7	9
22nd	July	N	7	8
23rd	July	NNE	26	7
24th	July	NNE	32	6
25th	July	NNE	27	7
26th	July	NNE	27	8
27th	July	NNE	18	8
28th	July	NNE	21	8
29th	July	NNE	23	8
30th	July	NNE	20	8
31st	July	NNE	22	9
1st	August	NNE	18	9
2nd	August	NNE	28	8
3rd	August	NE	38	8
4th	August	NE	45	9
5th	August	NE	40	9
6th	August	NNE	30	9
7th	August	NNE	18	9
8th	August	NNE	29	8
9th	August	NE	38	8
10th	August	NE	42	8
11th	August	NE	40	8
12th	August	NNE	30	8
13th	August	NE	41	9
14th	August	NE	45	9
15th	August	NE	46	9

Appendix 4 Winds speed and direction data in GNOME simulations

Table 5 Tripoli winds offshore (summer) at latitude and longitude location 33°49'56.93"N 11°56'30.30"E

day	Month	Direction	Direction/degree	Speed/knots
16th	July	NE	37	8
17th	July	NNE	29	8
18th	July	N	4	7
19th	July	N	355	8
20th	July	N	358	9
21st	July	N	350	9
22nd	July	NNW	338	7
23rd	July	N	351	6
24th	July	NNW	333	6
25th	July	N	350	7
26th	July	N	3	9
27th	July	N	4	9
28th	July	NNW	347	8
29th	July	N	355	8
30th	July	N	3	8
31st	July	N	1	8
1st	August	N	359	8
2nd	August	NNW	346	7
3rd	August	NNE	14	6
4th	August	NE	39	7
5th	August	NNE	20	8
6th	August	N	4	9
7th	August	N	350	9
8th	August	NNW	339	7
9th	August	NNW	347	7
10th	August	NNE	23	7
11th	August	N	2	8
12th	August	N	3	8
13th	August	NNE	14	7
14th	August	NNE	19	7
15th	August	NNE	24	8

Table 6 Tripoli winds offshore (winter) at latitude and longitude location 33°49'56.93"N 1°56'30.30"E

Day	Month	direction	Direction/degree	Speed/knots
16th	January	WNW	303	11
17th	January	NW	306	12
18th	January	W	269	11
19th	January	WNW	287	12
20th	January	NW	311	13
21st	January	NW	313	14
22nd	January	NW	310	15
23rd	January	WNW	283	15
24th	January	W	274	15
25th	January	W	274	15
26th	January	WNW	301	14
27th	January	WNW	285	13
28th	January	WNW	303	13
29th	January	NW	309	13
30th	January	NW	313	12
31st	January	NW	314	12
1st	February	NW	308	12
2nd	February	NW	316	14
3rd	February	NW	307	13
4th	February	NW	311	12
5th	February	NW	319	11
6th	February	WNW	286	11
7th	February	WNW	290	12
8th	February	NW	324	13
9th	February	NNW	327	14
10th	February	NW	307	15
11th	February	NW	314	15
12th	February	NW	317	14
13th	February	NW	322	13
14th	February	NW	313	12
15th	February	NW	309	12

Table 7 Misratah winds offshore (summer) at latitude and longitude location 33° 8'43.64 "N 1 °23'6.94 "E

Day	month	direction	Direction/degree	Speed/knots
16th	July	NNW	316	7
17th	July	NW	338	8
18th	July	NNW	337	8
19th	July	NNW	341	8
20th	July	NNW	336	8
21st	July	NNW	334	8
22nd	July	NNW	329	8
23rd	July	NNW	325	7
24th	July	NW	343	7
25th	July	NNW	334	8
26th	July	NNW	331	8
27th	July	NNW	332	8
28th	July	NNW	323	8
29th	July	NW	317	8
30th	July	NW	325	8
31st	July	NW	334	8
1st	August	NNW	341	8
2nd	August	NNW	344	7
3rd	August	NNW	324	6
4th	August	NW	315	6
5th	August	NW	312	7
6th	August	NW	334	8
7th	August	NNW	332	8
8th	August	NNW	324	7
9th	August	NW	314	7
10th	August	NW	310	7
11th	August	NW	321	8
12th	August	NW	330	7
13th	August	NNW	343	7
14th	August	NNW	351	7
15th	August	N	351	7

Appendix 4 Winds speed and direction data in GNOME simulations

Table 8 Misratah winds offshore (winter) at latitude and longitude location 33° 8'43.64 "N 15 ° 23'6.94 "E

Data	month	direction	Direction/degree	Speed/knots
16th	January	NW	313	12
17th	January	NW	307	12
18th	January	WNW	292	12
19th	January	W	268	13
20th	January	NW	322	14
21st	January	NW	312	14
22nd	January	WNW	301	15
23rd	January	WNW	283	16
24th	January	W	277	16
25th	January	W	278	15
26th	January	WNW	283	14
27th	January	NW	310	13
28th	January	NW	319	13
29th	January	NW	306	14
30th	January	NW	307	14
31st	January	NW	318	14
1st	February	WNW	294	15
2nd	February	WNW	297	15
3rd	February	NW	316	15
4th	February	NW	319	13
5th	February	NW	320	12
6th	February	NW	319	12
7th	February	W	279	13
8th	February	WNW	283	14
9th	February	NNW	335	15
10th	February	NW	311	16
11th	February	NW	318	17
12th	February	NW	308	16
13th	February	NW	321	15
14th	February	NW	310	14
15th	February	NW	315	14

Appendix 4 Winds speed and direction data in GNOME simulations

Table 9 Misratah winds on coast (summer) at latitude and longitude location 32°22'17.56"N 15°12'47.78"E

Data	month	direction	Direction/degree	Speed/knots
16th	July	NNE	19	7
17th	July	NE	34	8
18th	July	N	358	7
19th	July	N	355	7
20th	July	NNW	344	8
21st	July	NNW	344	8
22nd	July	NNW	340	8
23rd	July	NNW	341	8
24th	July	NNW	344	7
25th	July	N	349	8
26th	July	N	4	8
27th	July	NNE	11	9
28th	July	N	3	8
29th	July	NNW	337	8
30th	July	NNW	332	8
31st	July	NNW	340	8
1st	Aguste	NNW	345	9
2nd	Aguste	NNW	347	8
3rd	Aguste	N	1	7
4th	Aguste	NNE	22	7
5th	Aguste	NNE	11	6
6th	Aguste	NNW	344	8
7th	Aguste	NNW	344	9
8th	Aguste	N	353	8
9th	Aguste	NNE	13	8
10th	Aguste	NNE	32	7
11th	Aguste	NNE	17	8
12th	Aguste	N	8	8
13th	Aguste	N	5	7
14th	Aguste	NNE	19	8
15th	Aguste	NNE	12	7
16th	Aguste	NNW	344	8

Appendix 4 Winds speed and direction data in GNOME simulations

Table 10 Misratah winds on coast (winter) at latitude and longitude location 32°22'17.56"N 15°12'47.78"E

data	Month	direction	Direction/degree	Speed/knots
16th	January	WNW	302	12
17th	January	WNW	290	12
18th	January	NNW	340	12
19th	January	WNW	292	13
20th	January	N	355	14
21st	January	NNW	343	14
22nd	January	WNW	285	15
23rd	January	NW	308	15
24th	January	NW	305	15
25th	January	WNW	300	14
26th	January	W	277	13
27th	January	WNW	286	13
28th	January	NW	304	13
29th	January	WNW	299	13
30th	January	NW	314	13
31st	January	NNW	343	13
1st	February	NW	310	13
2nd	February	WNW	283	15
3rd	February	NW	314	14
4th	February	NW	318	13
5th	February	NW	320	11
6th	February	NW	310	10
7th	February	NNW	329	12
8th	February	N	5	13
9th	February	NNW	328	15
10th	February	NW	312	16
11th	February	NW	312	16
12th	February	NW	307	16
13th	February	WNW	297	12
14th	February	NW	305	13
15th	February	NNW	347	13

Appendix 5 Depth of Misratah coast

Table 1 maximum and minimum deep degree 20 m off shoreline along the coast

Coastal segment names	Distance from shoreline	shore death	Costal description
Dafnia	20M	15M	High gradient
Jazeera al –hamam	20 M	15 M	High gradient
Zurek	20 M	12 M	Medium gradient
Abo Fatima	20 M	8 M	Medium gradient
Aboruaia	20 M	6 M	Medium gradient
Aman beach	20 M	6 M	Medium gradient
Aljazeera beach	20 M	5 M	Medium gradient
Altoba	20 M	4 M	Medium gradient
Marbat	20 M	4 M	Medium gradient
Resort industries	20 M	10 M	High gradient
Soar Saud	20 M	5 M	High gradient
Gaser-ahmed	20 M	20 M	High gradient
Albonta	20 M	8 M	High gradient
Alroumia	20 M	5 M	Medium gradient
Aerar	20 M	3 M	Low gradient
Mahaboly	20 M	2 M	Low gradient
Marzouga	20 M	2 M	Low gradient
Almalafa	20 M	1.5 M	Low gradient
Buerat	20 M	2 M	Low gradient

Appendix 6 Legislative and regulatory framework

Environmental Laws and Regulations is a part of managing the coastal and marine environment,

Libya already has quite a number of laws that deal with oil activities and the environment generally. Libya has also signed international protocols with Mediterranean Sea countries

- International Environmental agreement
- National Environmental agreement

1- **International Conventions**

- International Convention for the Prevention of Pollution from Ships (MARPOL 73/78)
- International Convention on Oil Pollution Preparedness, Response and Co-operation
- CLC 1969 (amended with 1992 protocol)
- The United Nations Convention on the Law of the Sea (1982)
- Convention on Preservation of Fauna and Flora in their Natural State (London, 1933)
- African Convention on the Conservation of Nature and Natural Resources (Algeria , 1968)
- Convention on Wetlands (Ramsar, 1971).
- Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona, 1976)
- Convention on the Conservation of Migratory Species of Wild Animals (Bonn, 1979)
- United Nations Convention on the Law of the Sea (UNCLOS) (Montego, 1982).
- Convention on Biological Diversity (Rio, 1992).
- Cartagena Protocol on Biosafety to the convention on biological diversity (Montreal, 2000).

2- National Legislation :

Law for Protecting and Improvement of the Environment No. 15 1371 (2003) sets the framework for environmental protection and sets out methods for pollution measurement and plans and programs for pollution elimination. The Law specifies the duties of the public towards preserving the environment in the following relevant fields:

- Informing the competent body pollution has occurred
- Cooperation with international bodies for the removal of pollution
- Protection of Atmosphere
- Protection of Seas and Marine Wealth
- Protection of Water Resources
- Protection of Wildlife
- Protection of Sea and Marine wealth (Articles 18 – 38)
- Protection of Water Sources (Articles 39 – 47)