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Factors for Consideration in a Plan for Terrestrial Oil Disaster Mitigation

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Abstract

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MS, Boston University, 2015

MS, Saint Mary's University, 2008

MS, University of Ibadan, Nigeria, 2003

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Professional Administrative Study Submitted in Partial Fulfillment

of the Requirements for the Degree of

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Abstract

Oil spills, are common disasters associated with hydrocarbon exploration and production, can be devastating and severely impact water quality, which can be detrimental to human life and the environment. One of the primary objectives of oil spill planning and response, aside from protecting human beings, is to reduce the environmental consequences of spills and cleanup efforts. This objective is best achieved by responders identifying sensitive resources ahead of time to establish protection priorities and select cleanup strategies. When a plan is well situated, within the limited hours available to respond, responders will not have to contact all of the various resource managers for information on essential resources to protect. That means that the effectiveness of the Environmental Sensitivity Index (ESI) map of an area depends on the integral component of overall planning activity. This qualitative study explored and used publicly available and nonproprietary data to mimic the coastal and marine sensitivity representations on emergency preparedness for environmental disaster in terrestrial settings and produce a plan to address such potential disaster. Results indicate that there is a need to classify the resources that society values, such as biological, socioeconomic, or cultural assets, and describe the state of a system and the degree to which a system or asset is affected, either positively or negatively, in the event of an oil spill. Terrestrial Environmental Sensitivity Index mapping will help to support the highest response priorities, prevent impacts to human life, prevent oil from leaching into groundwater or as runoff, and return the environment to productive use as quickly as possible, leading to positive social change.

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Dedication

I want to dedicate this research to my aged parents, my beautiful wife, and our three boys. My parents, especially my mother, always want to get me occupied; she will go out of her way to register me for one vocational training class when the school is not in session to prevent me from traveling here and there. And Dad makes the funds available from bachelor's to master's degree. Though you are not physically right here by my side due to distance, I am happy to showcase what your beliefs and teachings have gotten me. You have been and always will be my hero.

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Section 1: Introduction to the Study

Introduction

West Texas houses the sedimentary basin called the Permian, which contains some of the nation's most extensive oil and gas resources (Donaghy, 2019). The Permian Basin is a grassy oil-drilling region extending west to the Pecos River within the Big Bend Country in Texas (Wikitravel, 2016). A 2018 resource assessment from the U.S. Geological Survey projected the total of undiscovered, technically recoverable resources (UTRR) in the Permian to be 70.5 billion barrels of oil, 339.8 trillion cubic feet of natural gas, and 22.7 billion barrels of natural gas liquids. According to Trout and Stockman (2019), carbon emissions from Permian oil and gas production through 2050 could alone exhaust nearly 10% of the global 1.5°C carbon budget. Therefore, transporting oil and its derivatives from production sources to consumption locations entails risks, most notably, the risk of accidental oil spills, which can cause severe damage to ecosystems and loss to human society (Chang et al., 2014).

The western part of Texas is considered an extraction colony for the rest of the world's fuel resources. Oil transportation will continue to be on the rise, and many communities are at risk of oil spill disasters (Chang et al., 2014). There is a need to have a plan dedicated to deepening understanding of the interactions between oil, fragile ecosystems, the environment, and the impacts of oil on human settlements that are vulnerable to spill events (Nelson & Grubesic, 2018). Such advances in oil spill index mapping and associated analytics will increase the efficiency of spill interdiction and mitigation efforts and nurture proactive versus reactive response strategies and plans for local and regional stakeholders (Nelson, & Grubesic, 2018). In an ecosystem, oil spills can be devastating and severely impact water quality, which could be detrimental to human life and the environment. In other words, accidents involving oil spills in the terrestrial or marine environment can cause several impacts on biological communities and impose severe damages on human-use resources.

One of the primary objectives of oil spill planning and response, aside from protecting human life, is to reduce the spill's and cleanup efforts' environmental consequences. Emergency responders can best achieve this objective if the location of sensitive resources is identified in advance so that protection priorities can be established, and cleanup strategies can be selected. When this plan is well situated, the responders will not have to contact all of the various resource managers for information on the essential resources to protect within the limited hours available. That means that the effectiveness of Environmental Sensitivity Index (ESI) mapping in an area depends on the integral component of overall planning activity.

ESI mapping is a widely used approach in coastal and marine environments across the globe. It gained more popularity after the Deepwater Horizon oil spill of 2010 (Nixon et al., 2016; Sealey & Patus, 2015). A substantial body of research focused on its further development (Nelson & Grubesic, 2018). In this paper, the aim is to develop a plan to adopt this idea in the terrestrial environment of West Texas, to classify the resources that society values such as environmental, socioeconomic, or cultural assets (Berenshtein et al., 2019) and describe the state of a system and the degree to which assets are affected by a given disaster, especially an oil spill (Nelson & Grubesic, 2018).

Problem Statement

The Railroad Commission (RRC) of Texas is the oldest regulatory agency in the state and is one of a kind. RRC was initially established in the year 1891 under a constitutional and legislative mandate to prevent discrimination in railroad charges, establish reasonable tariffs, and regulate the private railroads spreading across the state (RRC, n.d.). Over the years, the commission's jurisdiction has grown to encompass many activities such as oil and gas production and transportation in the year 1919, gas utilities in the year 1920, liquefied petroleum gas in the year 1939, surface mining and reclamation in the year 1976, and alternate fuels research in the year 1991. Year 2005 brought about regulatory changes; the Rail Division and its remaining function, rail safety regulation, were transferred to the Texas Department of Transportation (RRC, n.d.).

Simultaneously, the state's oil and gas industry remain the primary focus of the RRC of Texas (RRC, n.d.). RRC, through its Oil and Gas Division, regulates the exploration, production, and transportation of oil and natural gas in Texas. The commission is also saddled with the following responsibilities:

1. prevent waste of the state's natural resources,
2. protect the correlative rights of different interest owners,
3. prevent pollution, and
4. provide safety in matters such as hydrogen sulfide (RRC, n.d.).

According to Worland (2019), there are approximately 466,623 miles of pipelines across Texas, transporting hazardous liquids, natural gas, and petroleum throughout the state. Around the state, large industrial tankers transport oil, gas, and other fuels on the road. Unfortunately, these petrochemical transportation methods could quickly fail, causing horrific disasters that could destroy the environment and cause injuries or even deaths to oil workers and residents due to delay in response time. Oil spills onto land are relatively common. Between 1989 and 1995, about 3,500 spills per year were reported in Canada (Environment Canada, 1998). About 42% of the spills occurred in the vicinity of production wells, while 29% were from pipelines and 16% were from tanker trucks. In another study of the period 2000 to 2011, a total of 1,047 spills were reported from oil or gas pipelines in Canada (Kheraj, 2013).

The problem is that prospecting, extraction, and oil transportation often result in accidental oil spills or pipeline leakage. RRC, being a state regulatory agency, does not have a similar plan to that of the coastal and marine environments to respond to these potential emergencies. Land and terrestrial habitats are potentially vulnerable to oil spills, with possible negative consequences including damage to biological resources, cultural and economic objects, and nature conservation territories. In this regard, developing plans for addressing potential terrestrial environmental disasters using a Geographic Information System (GIS) is deemed necessary and incredibly urgent. These plans, if developed into GIS tools such as a sensitivity map, would help in oil spill response (OSR) activities and minimize oil spills' potential damage to natural and human-made environments (Shavykin & Karnatov, 2018). Sensitivity maps represent how sensitive the land and shoreline are to oil, as ranked by the ESI (Berenshtein et al., 2019).

Purpose of the Study

Conducting and guiding disaster contingency planning requires the ESI map element. Road transport and the pipeline network are the primary vectors in accidents that cause oil spills in the land environment. The National Oceanic and Atmospheric Administration (NOAA) originally conceived oil spill ESI maps for coastal and marine environments. This approach was later extended into other aquatic environments such as rivers, lakes, and swamps (NOAA, 1995). There was no prior consideration for land environments that might be polluted by oil spill events (Martins et al., 2018). The evidence toward this current bias is the consolidation of methodologies oriented for the elaboration of oil spill ESI maps for aquatic environments, while those directed toward the terrestrial environments are rarely analyzed (Martins et al., 2018).

This qualitative study was aimed to explore and make use of publicly available and nonproprietary data to mimic the coastal and marine sensitivity representations on emergency preparedness for environmental disasters in terrestrial settings and produce a plan for RRC to address such potential disasters. One proposed solution is to develop a Terrestrial Environmental Sensitivity Index (TESI) map, a GIS tool to classify resources based on the sensitivity and relative significance of environmental and cultural assets in the region (Steadman et al., 2004). This study may contribute to the efficacy and design of such a proposed product for RRC.

Due to an increase in oil reserves and recent increase of oil discoveries in West Texas (Sanderson et al., 2019), coupled with future world and U.S. oil production, oil transportation should be a concern in planning. Roads and pipelines seem to be the most likely modes of transportation of oil derivatives in West Texas during the coming decades, given that they are already intensively used within an extensive and comprehensive network covering most West Texas territory (Government Accountability Office [GAO], 2014). Thus, environments adjacent to road and pipeline networks are regarded as essential areas in the plan for oil spills' sensitivity. This plan would help the state regulatory agency develop an environmental sensitivity map concerning oil in terrestrial environments associated with pipeline networks and road transportation.

Research Questions

Through this study, I sought to explore the following research question: What factors should be considered in the design of a plan for RRC to mitigate emergency terrestrial oil spills more quickly?

Nature of the Study

This study used a qualitative approach to address the research question. ESI maps mostly form the basis for establishing protection priorities. Therefore, this study involved gathering necessary information by exploring public data and other nonproprietary resources. The study also adopted the following steps in creating a plan for a digital ESI database using GIS technology (Jensen et al., 1998; Norwegian Environment Agency & United Nations Environment Programme—World Conservation Monitoring Centre [NEA & UNEP-WCMC], 2019):

- Collect baseline data, documenting the location of biological, human use, and environmental resources.
- Compile the information onto maps and tables, digitize spatial data, and attribute data into specified digital formats.
- Perform an initial classification of terrestrial environmental sensitivity and produce the initial ESI maps and attribute tables.
- Review and incorporate edits, make final ESI atlas and tabular products, and get the digital products ready (including metadata) for dissemination.

There is an application of the NOAA system and its variations to environmental sensitivity to the oil in several places. Jensen et al. (1993) established it as an efficient tool in oil spill events. The mapping of terrestrial environmental sensitivity to oil must, at least, contain the same factors as those required in the NOAA system to facilitate the integration of adjacent areas with a variety of environments comprising any of the five major terrestrial ecosystems: desert, forest, grassland, taiga, and tundra (Smith, 2019). Data collection and cartographic representation mode may be integrally applied to the mapping of terrestrial sensitivity to oil spills.

The sensitivity of a given element to oil captured is indicated by a specific color-coded ribbon and represented with a unique symbol on TESI maps (Jensen et al., 1990). This type of symbolization is recommended for effective cartographic communication. Indeed, because decision makers and managers are not geographers or computer professionals (Choriey, 1988), it is imperative to make sure that the symbolization of the terrestrial ESI remains easily understood.

Data Source

In the mapping of coastal environments, biologically sensitive resources are only related to fauna (e.g., nesting sites, breeding areas, nurseries, feeding areas) because vegetation is already intrinsically represented by ESI, both closely correlated factors. Thus, land use and land cover mapping compose the TESI. Land cover is a crucial element in oil spill events in terrestrial environments, in that the oil may reach biological and socioeconomic components, depending on the type of land cover.

According to Martin et al. (2018), impact on the biota is less likely in areas with established artificial land cover. Contrastingly, the socioeconomic environment is the most impacted factor. On the other hand, the biota will certainly be impacted in forest/woods areas. The adequacy of the land cover item to the map of environmental sensitivity to oil may be achieved in two ways (Martins et al., 2018): (a) through the availability of a land cover map annexed to the sensitivity map and (b) land cover as an auxiliary index connected to TESI.

This research involved the use of physical and geomorphic features (e.g., topography), biological characteristics, and socioeconomic features such as agricultural fields categorized based on their sensitivity to oil. This study also used relatively high spatial resolution satellite data for the planimetric detail (Jensen et al., 1998; Jensen et al., 1990). Other information needed for sensitivity maps can be obtained from existing scientific publications, topographic maps, photographs, and environmental data held by organizations such as the RRC, government departments, universities, and conservation groups.

Plan for Data Acquisition

Most of the needed data were extracted through ArcGIS digitization of existing digital and hardcopy materials, which could be aerial photos, topographic maps, and so on. Because the digitization of topographical types, biological resources, and human-use resources is a complex and highly quality-controlled process (NOAA, 2020), the digitization was facilitated by splitting the entire study area into individual quadrangles using the index data layer.

The ESI digitized terrestrial layer was checked regularly for completeness and topological and logical consistency using both on-screen and hardcopy reviews, so that any error in the terrestrial classification could be updated before the digitization of the biological and human-use layers. Spatially, all of the layers used the terrestrial data as the geographic reference so that there were no slivers in the geographic coordinates (NOAA et al., 2000).

The hardcopy biological information was compiled onto 1:25,000 U.S. Geological Survey (USGS) topographic quadrangles using data from the region in the form of maps, tables, charts, and written descriptions of wildlife distributions. Concurrently, the digital data were imported, projected, checked for quality control, and integrated into the data structure. The digitized and verified data were combined with existing data, plotted, and reviewed. Then, the data were merged to form the study-wide layers. The data merging included a final quality control check where labels, chains, and polygons were checked for attribute accuracy (NOAA et al., 2000).

Significance of the Study

The finalized plan aids sensitivity ranking, integration, and mapping. The sensitivity maps facilitate identifying the most sensitive and exposed locations, combining several sensitivities through the map's direct visual study or cross-analysis using a GIS (International Petroleum Industry Environmental Conservation Association [IPIECA] et al., 2012). Identifying the most sensitive sites would guide this list of places to develop a realistic oil spill response strategy. The plan requires the regulatory agency to conduct the prioritization process with the main stakeholders (e.g., city, county, and state) to discuss protection and clean-up priorities openly. When a consensus is reached on the prioritization, the sensitivity maps must be validated at a high level in the organization and integrated into the contingency plan as an operational planning and decision support tool (IPIECA et al., 2012).

The main advantages of terrestrial environmental sensitivity mapping are that it shows where various resources are and indicates environmentally sensitive areas. Environmental scientists can use it to respond to emergencies and make decisions about land development, disaster response, and planning, as well as to assess the environmental impact of real or hypothetical events. Scientists and experts can use it without special GIS skills. At the touch of a button, they can create a significant number of sensitivity maps.

Summary

According to Chang et al. (2014), one of the most important predictors of impact is the location where a spill event occurs. Spills closer to human populations have more significant economic effects and are more expensive to clean (Chang et al., 2014). Apart from protecting human life, one of the primary objectives of oil spill planning and response is to reduce spill and cleanup efforts' environmental consequences (Jensen et al., 1998). A plan toward developing a sensitivity index proper to terrestrial environments made possible the systematization of an index to be efficient, quick, and simple to produce a map, addressing potential terrestrial environmental disasters. Suppose the location of sensitive resources is identified in advance. In that case, the responder can establish protection priorities and cleanup strategies (Jensen et al., 1998), resulting in the improvement of human and social conditions and society's betterment.

In Section 2, I present a literature review on plans for addressing potential coastal environmental sensitivity index mapping from different locations across the world and mimic them to create a hypothesis and process to conduct the same research for the terrestrial environment of the West Texas area.

Section 2: Conceptual Approach and Background

Introduction

This research investigated the factors to consider in designing and developing a plan to address potential terrestrial environmental disasters using GIS. The application of the NOAA system and its variations to environmental sensitivity to oil in several places in the world (Adler & Inbar, 2007; Castanedo et al., 2009) establishes it as an efficient tool in oil spill events.

The mapping of terrestrial environmental sensitivity to oil must, at least, contain the same factors as those required in the NOAA system to facilitate the integration of adjacent areas with a variety of environments comprising terrestrial, coastal, and freshwaters (Martins et al., 2018). Two types of environments, namely, biologically sensitivity to oil and the human use of commercial, recreational, or subsistence resources, are replicable in any sensitivity mapping (Martins et al., 2018). This study integrated data collection and cartographic representation mode to terrestrial mapping sensitivity to oil spills.

The only component of the NOAA systems that may not directly apply to terrestrial environments is ESI. The resultant effect of the mode at which ESI is conceived and evolved, with its range of applications to aquatic habitats, mostly marine and coastal ones, results in specific variables, such as exposure to waves, which do not apply to terrestrial environments (Martins et al., 2018). Therefore, a comprehensive adjustment of the index system based on parameters consistent with the terrestrial environment and respective oil dynamics in these environments is deemed necessary. This study's main contribution comprises such an adaptation.

Concept, Model, and Theories

According to Sealey and Patus (2015), ESI maps were initially hand-drawn over topographic maps. Scientists ranked the areas along the shore according to their vulnerability to oil spills. The concept was to quickly pull together expert information and existing data on a map for oil spill response planning—this information cut across portfolios in different agencies and organizations. Scientists, coastal managers, clean-up contractors, and oil companies used this map for both oil spill preparedness and response activities.

Over the years, scientists gathered more information on the predictable and regular changes that occur every calendar year, alongside the mating and production of offspring by animals that could affect protection priorities. However, advanced GIS technology facilitated the easy production and distribution of ESI maps (Jensen et al., 1998) significantly. The 1989 Exxon Valdez oil spill in Prince William Sound, Alaska—the largest in U.S. history, which tested the abilities of local, national, and industrial organizations to prepare for and respond to a disaster of such magnitude (U.S. Environmental Protection Agency [EPA], 2017)—had a significant impact on the demand for ESI maps. After this, two fundamental changes took place. For the first time, the public and supporting volunteers for wildlife rescues were concerned about the damage that oil caused (Sealey & Patus, 2015). Second, this public awareness brought ESI maps to a broader audience, supporting essential laws and funding initiatives that mandated oil spill prevention and response strategies (Sealey & Patus, 2015). ESI map popularity gained more ground after the 2010 Deepwater Horizon oil spill (Nixon et al., 2016; Sealey & Patus, 2015).

GIS technology and its advanced database made it practical and easy to collect more information about species vulnerabilities to oil spills. This effort made ESI maps with their associated datasets more accessible even on the field via handheld devices for rapid responses. There are two primary purposes for ESI maps in West Texas. First, oil spill response teams need to know which species occur and their respective locations. Today, West Texas is at risk for oil spill impacts from the transportation of petroleum products moving through the region. This paper presents a plan for West Texas's ESI map development by mapping the terrestrial environment. The composition that is compatible with NOAA ESI standards is a critical step in oil spill response planning, integrating information from scientific reports, interpreted images, and field surveys.

Terrestrial Environmental Sensitivity Index

According to Petersen et al. (2002), the research that launched ESI and the currently dominant NOAA defined the index based on the physical processes controlling oil deposition, persistence, or longevity in the environment plus the extent of biological damage. The natural hydrocarbon-based substances and refined petroleum products have different chemical compositions and distinct physical properties that affect how oil behaves, spreads, and breaks down when it encounters the earth's surface (U.S. EPA, 2016). There are hazards that an oil spread may pose to marine and human life, along with likely threats to natural and human-made resources (Aguilera et al., 2010; Burton et al., 2010; U.S. EPA, 2016). For example, gasoline and kerosene, light refined products, spread on wet surfaces and percolate porous soils quickly. Though the products evaporate quickly and leave little residue, fire and toxic hazards are high. A heavier refined product may not spread as readily and poses a lesser fire and deadly threat. Nonetheless, the heavier refined products are more persistent, and remediation tends to be challenging (Hubbe et al., 2013).

The rate at which an oil spill spreads determines its impact on the environment (U.S. EPA, 2016). In most cases, oils spread horizontally into a smooth and slippery surface called a *slick* on top of the water. Many factors affect an oil spill's spreading ability, such as surface tension, specific gravity, and viscosity (Hubbe et al., 2013; U.S. EPA, 2016). Surface tension is the measure of attraction between the surface molecules. The higher the oil's surface tension, the more likely it is that a spill will remain in place. If the oil's surface tension is low, the oil will spread even without help from wind and water currents. Because increased temperatures can reduce a liquid's surface tension, oil is more likely to spread faster in a warm than in a frigid environment (U.S. EPA, 2016).

According to Drummond and Israelachvili (2004), crude oil's surface tension is affected by its constituents' amounts and chemical nature. Specific gravity is the density of a substance compared to water density. Because most oils are lighter than water, they lie flat on top. An oil spill's specific gravity can increase if the more lightweight substances within the oil evaporate (U.S. EPA, 2016). In contrast, viscosity is the measure of liquids' resistance to flow. The higher the oil's viscosity, the greater the tendency to stay in one place (Hubbe et al., 2013; U.S. EPA, 2016).

To correctly evaluate oil spill vulnerability in an area lying along a shore, it is crucial to understand detailed geomorphic and grain size variability (NOAA, 2002); this requires more attention in continually changing landforms (Grottoli & Ciavola, 2019). One can achieve the geomorphological characterization by identifying segments of interest or sections of study areas with homogeneous characteristics (Martin et al., 2018).

The development of an environmental Sensitivity Index for terrestrial environment TESI follows a similar pattern (Martins et al., 2018).

The terrestrial environment segment breakdown represents a terrain area with similar physical environmental properties (Martins et al., 2018). The study area would be in separate polygons corresponding to terrain areas consistent with the terrestrial ecosystems, carved out in zones rather than in one line, in contrast to most coastal sensitivity representations. Each zone would be prioritized and ranked to differentiate the relative sensitivity and importance of different assets by area. The final method for locating and prioritizing sensitive regions and assets would be subject to stakeholder consultation and broader engagement to understand the needs and concerns of those affected by decisions, defining a set of agreed-upon criteria (Carey et al., 2014). In case there are some sensitive assets of ecological importance that are not recognized as valuable by stakeholders, they may be included (NEA & UNEP-WCMC, 2019).

In addition, Martins et al. (2018) proposed five critical variables that control oil dynamics in terrestrial environments: (a) slope, (b) soil texture, (c) soil depth, (d) water table depth, and (e) density of drainage. The incorporation of these variables enhances the development of the TESI (Martins et al. 2018). Low, intermediate, and high are further classifications of each variable attributed to a specific color. Then, TESI can be defined by a set of five partial sensitivities, one for each key variable, with their respective systematization procedure and equivalent conceptual correlation.

Slope

Among other properties inherent to each type of oil and oil derivatives, viscosity and density interfere with the oil spill’s behavior (Santos et al., 2014). Because of the small density and higher viscosity nature of oil, it is easy to absorb soil surface, affecting soil permeability and soil porosity (Wang et al., 1999). Table 1 highlights the oil derivatives and their associated viscosity, ranging from low to high.

Table 1

Parameter ξ for Different Types of Fluids

Fluid	ξ parameter
Low viscosity (e.g., gasoline, petrol)	0.5
Medium viscosity (e.g., kerosene, gasoil, paraffin, and diesel)	1.0
High viscosity (e.g., light fuel oils)	2.0

Note. Adapted from *Fast Prediction of the Evolution of Oil Penetration Into the Soil Immediately After an Accidental Spillage for Rapid-Response* Purposes [Paper presentation], by S. Grimaz, S. Allen, J. Stewart, and G. Dolcetti, May 11–14, 2008, 3rd International Conference on Safety & Environment in Process Industry, Rome, Italy (https://www.aidic.it/CISAP3/webpapers/21Grimaz.pdf).

If the soil is impermeable, the oil will flow in alliance to the surface's downward slope, which means that steep slopes hold very little oil (Etkin et al., 2007). So, taking the gentle slope class as a reference, the oil depends on the soil's hydraulic conductivity and moves in the subsoil direction. In contrast, the soil with a steeper slope has a higher hydraulic conductivity; hydraulic conductivities generally decrease downward (Hu et al., 2008). Therefore, the flow of oil derivatives in steep slope terrain will follow the soil topography due to the liquid nature of oil and gravity, even with the landscape subject to the surface layer's permeability.

In a nutshell, slopes can play a vital role in tackling an oil spill emergency because the responder can easily estimate the direction of the oil flow at the time of the accident, with the view that the surface's downward slope may indicate the direction of the oil flow in slope areas (Etkin et al., 2007). Though the impacted site could be less extensive than the contaminated horizontal area, high slopes imply lower environmental sensitivity. This view governs the ease of cleaning and remediating a place so that oil does not reach an acute vertical displacement, a situation in which the oil will percolate the saturated zone, thereby increasing the volume of pollution (Martins et al., 2018).

Soil Texture

Soil texture refers to the relative proportions of sand, silt, and clay particles in a soil mass, determining soil retention and permeability (Oyem & Oyem, 2013). These two properties influence the dynamics of oil in the soil, making it possible to correlate particle size with its respective intrinsic impact. Loamy soil will remediate faster than sandy or heavy clay soil because sand particles fail to compact easily, unlike clay particles that are small, align easily, and are sticky, especially when wet (North Carolina [NC] State Extension, 2018). In general, compaction inhibits fluid movement because compacted soils have less infiltration but more significant runoff and drain very slowly. On the other hand, silty loam particles are light and not sticky (NC State Extension, 2018).

Table 2

Coefficient and Level of Permeability as a Function of the Type of Soil Texture

Coefficient of permeability	Level of permeability	Soil texture type

> 10^{-1}	High	Stone, gravel, coarse and medium sand
10^{-1}–10^{-3}	Medium	Uniform medium sand and fine sand
10^{-3}–10^{-5}	Low	Uniform fine sand, silt, and clay

Note. Adapted from *Design Guide for Oil Spill Prevention and Control at Substations* (Bulletin No. 1724E-302; p. 34), by U.S. Department of Agriculture, 2008 (https://www.rd.usda.gov/files/UEP_Bulletin_1724E-302.pdf).

Soil permeability, also called *hydraulic conductivity*, is mainly controlled by soil structure and texture (Hu et al., 2008). Oil penetration and oil retention vary inversely. Materials composed of small grains are less permeable; highly permeable sediments have low retention and low permeability sediments have high retention (Etkin et al., 2007). Table 3 shows the correlation between grain size and oil retention capacity. The measurement of the size distribution in a collection of grains of the soil material corresponds to that soil's greater retention capacity. The relationship between the soil's retention capacity and environmental damage is similar to permeability. The greater the grain size, the more significant the vertical dispersion, or rather, the greater depths reached by the oil (Martins et al., 2018), and the environment will be more sensitive. The harder it is to remove it, the more the possibility of other impacts, such as oil reaching the water table, increases. Therefore, the correlation between soil texture and environmental sensitivity to oil spills is very likely to be direct. In areas where the grains composing the soil profile are the smallest, there exists the lowest sensitivity.

Table 3

Retention Capacity Coefficient R for Different Types of Soils

Soil typology	Retention capacity—R(m^3_{NAPL} m^{-3}_{soil})
Stone–Coarse gravel	5×10^{-3}
Gravel–Coarse sand	8×10^{-3}
Coarse sand–Medium sand	15×10^{-3}
Medium sand–Fine sand	25×10^{-3}
Fine sand–Silt	40×10^{-3}

Note. Adapted from *Fast Prediction of the Evolution of Oil Penetration Into the Soil Immediately After an Accidental Spillage for Rapid-Response Purposes* [Paper presentation], by S. Grimaz, S. Allen, J. Stewart, and G. Dolcetti, May 11–14, 2008, 3rd International Conference on Safety & Environment in Process Industry, Rome, Italy (https://www.aidic.it/CISAP3/webpapers/21Grimaz.pdf).

Soil Thickness

Fu et al. (2011) described soil thickness as the depth from the topsoil profile to the weathered bedrock. It could also result from the balance between the soil production rate and transportation (Dixon et al., 2009). Soil thickness denotes a critical attribute of many hydrological and ecological processes (Dietrich & Perron, 2006). Geomorphologically, soil thickness is crucial in determining hillslope stability, drainage area, and channel initiation (McNamara et al., 2006). Soil thickness appeared to be one of the most complicated aspects of the oil's environmental sensitivity because soil texture and depth of the water table are other direct dependent variables (Martin et al., 2018).

When dealing with oil spills in an environment with a thin soil profile, the crucial problem could be that the contaminant may easily reach a fractured rock. It is neither technically possible nor economically viable to retrieve detailed information for a complete description of such a fractured rock system. Moreover, complications in areas with thin soil profiles may occur due to how difficult it is to remove soil by mechanical excavation to clean and recover an area. Even when the excavation method seems to be the most economical method for the remediation of contaminated sites, it may not be possible in places with rocky outcrops (Martins et al., 2018). This condition dictates the high sensitivity factors associated with thin soil profiles and the challenges posed to the remediation of such environments (Martins et al., 2018). However, applying different cleaning and remediation methods in deep soils could reduce the possibility of reaching a fractured rock layer (Martins et al., 2018).

Cleaning and remediation could be challenging because oil can travel deeper and quickly in a fractured region; therefore, soil's retention capacity could be deficient (Martins et al., 2018). So, connecting the variables highlighted above, there is a possibility of establishing the environmental sensitivity to oil categorically. An environment with low slope, sandy, and shallow soil showcases a high sensitivity to oil spills, especially when it meets the applicable criteria of fast vertical displacement of the contaminant cum less approving preparation for the natural containment and established procedure of oil removal (Martins et al., 2018).

Water Table

The water table is another variable, probably the most considered when dealing with how sensitive an environment could be to the oil spill. Most applied procedures for oil removal in the soil lying immediately under the surface soil focus on the water table because water is either treated as an asset to be protected or as a targeted vector of oil trajectory (Martins et al., 2018). The water table is relevant, primarily if the oil runoff moves towards rivers, lakes, fishing areas, farmlands, conservation units, different water sources, supplies, etc.

Since the U.S. largest population relies on groundwater for roughly 25% of their freshwater (Allison & Mandler, 2018). This groundwater's location lies in porous and permeable rocks called aquifers that often lie close to the earth's surface – the deepest freshwater aquifers are found more than 6,000 feet underground (Allison & Mandler, 2018). Still, most are much shallower, from near the land surface to a few hundred feet below the surface (Allison & Mandler, 2018). Therefore, it is imperative to appraise the connection between environmental sensitivity and water table depth. The shallower the unsaturated zone, the easier it will be to reach the water table. If the spilled oil infiltrates the soil profile, it will critically get to the groundwater instead of retaining it in the less permeable layer (Martin et al., 2018).

A primary property of concern is the density of the immiscible liquid (oil in this case) in comparison to that of water (Artiola, & Brusseau, 2019). Once the oil reaches under the earth's surface waters, the oil may be carried off to other regions by the water current (Ji et al., 2020). However, this movement is dependent on the type of oil (light non-aqueous phase liquid - LNAPL; or dense non-aqueous phase liquid - DNAPL). These NAPLs are essential properties that classified immiscible liquids based on whether they are dense than water or not (Artiola & Brusseau, 2019). Upon releasing NAPL to an environment, either light (LNAPL) or dense (DNAPL), it will first migrate downward under the force of gravity. Because DNAPLs are denser than water, they can sink below the water table with enough release volume. In contrast to DNAPLS, LNAPLS float on the water table because they are less dense than water (Artiola & Brusseau, 2019). With the considerable increase in the environment's sensitivity, oil could either float close to the water level, following the hydraulic flux, or moves in other directions when oil monticules are formed (Martins et al., 2018).

The percolation or fluctuations of the groundwater can leach soluble components (Martins et al., 2018). In the same way, millions of gallons of leachate can percolate through a landfill (Artiola & Brusseau, 2019). Groundwater percolation or fluctuation is another situation that increases environmental sensitivity concerning the water table; thus, water table depth as a variable in the environmental sensitivity to oil becomes a crucial factor in any environmental analysis that involves petroleum and its derivatives (Martins et al., 2018).

Drainage Density

The variables proposed for the composition of the TESI may be incomplete without drainage density, measuring the sum of the channel lengths per unit area (Moglen et al., 1998). Drainage density also indicates how dissected the landscape is by channels. It has a close link to several hydrologic processes such as infiltration, soil saturation, overland flow, and their interactions that control runoff production and sediment (Moglen et al., 1998). Still, drainage density is not outrightly a simple function of precipitation. But an expression of the interrelationship of climate, soil geology, and vegetation (Moglen et al., 1998).

There is also a close relationship between drainage density and permeability; in general, low drainage density is typical in regions of highly resistant or highly permeable subsoil material, under dense vegetative cover, and where relief is low. In contrast, high drainage density is standard in weak or impermeable subsurface materials: sparse vegetation and mountainous relief (Moglen et al., 1998). Thus, higher drainage density corresponds to a higher permeability. The above correlation is correct because drainage in crystalline areas is very much conditioned by fracturing, and oil tends to migrate between the fractures. Consequently, several fractures, which will condition the drainage, indicate the environment's high permeability. Suppose oil spills onto a solid crystalline area, such as granite or gneiss, with a high density of drainage conditioned by fractures. In that case, there will be a significant probability that the oil reaches great depths (Martins et al. 2018, Moglen et al., 1998).

Ranking and Prioritizing Sensitive Sites and Resources at Risk

The relative sensitivity and importance given to each specific resource at risk in this concept could differ from one area to another; that is; assets with high priority may be considered low to medium importance in other areas (IPIECA et al., 2012). Therefore, there is no recommended single method for locating and prioritizing sensitive sites and resources. The goal is to establish a general ranking for each of the three resource types included in the sensitivity maps.

- the variable type and its general environmental sensitivity
- the sensitive ecosystems, habitats, species, and vital natural resources
- the sensitive socio-economic features

It is imperative to rank the sensitivity information on each of these themes using a method defined on a case-by-case basis. The ranked sensitivity information obtained is then mapped on an integrated map to identify the most sensitive sites. To rank the sensitivity information, there are various methods available (IPIECA et al., 2012):

- mathematical modeling of the sensitivity, using multiple indices
- aggregating the sensitivity information into one index
- using a map-based approach to simplify and rank the sensitivity information

However, there are peculiar pros and cons associated with each method, and limited data could also lead to a choice of methodology constraint. But because implementing a map-based approach is user-friendly and straightforward, decision-makers widely accept its usage. Below highlight the three simple steps involved in this methodology. The sensitivity information on the sensitivity map, type and sensitivity of variables, biodiversity-sensitive elements of the area, and socio-economic features would be the basis.

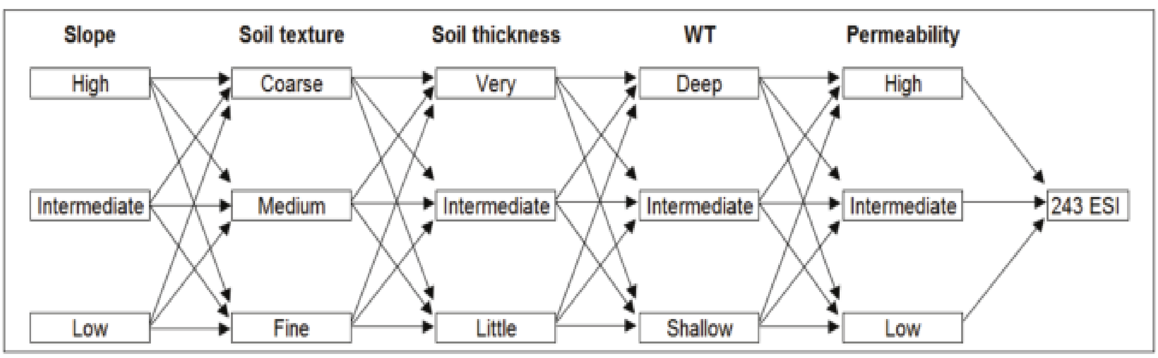
Step 1: Ranking of the Sensitivity of the Variable Types

The ESI already ranks the environmental sensitivity of the variable into 10 levels. These can be simplified into 3 classes, keeping only the most sensitive types of variables for the map. There are five variables with three classes in this variable index for terrestrial mapping, which eventually formed 243 different composites adopting three levels of full factorial response surface methodology (Figure 1). The three-level design is written as a 3k factorial. It means that k factors are considered at three levels (Wagner et al., 2014). One can refer to these levels as low, intermediate, and high or numerically express as 0, 1, and 2.

In contrast, a graphical analysis could reduce this number to something very close to the ten classes of the NOAA ranking (Martins et al., 2018) as mentioned earlier. Different color is assigned to each sensitivity level, green for low, yellow for intermediate and red for high sensitivity. Eventually, the method could reduce the possible composites to 21, as shown in figure 2, based on the interval of crucial variables used and employing the application of five pilot areas in the West Texas area.

Figure 1

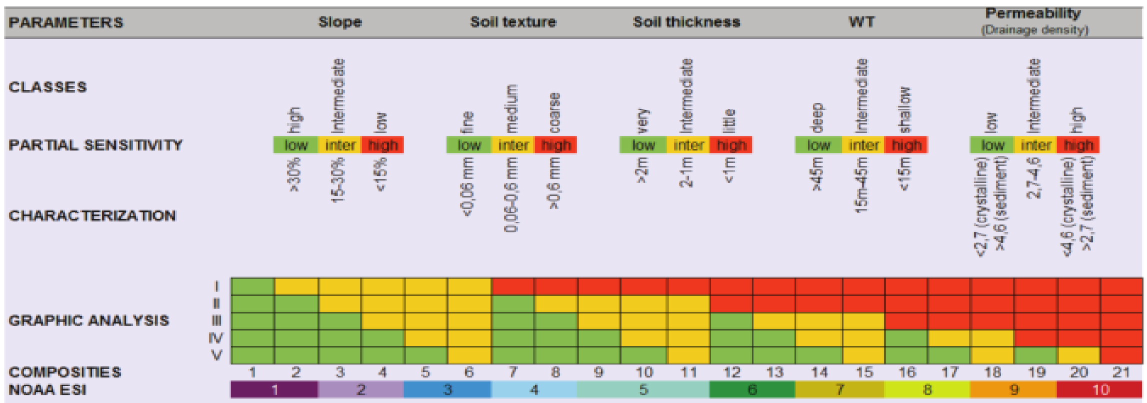
Variable Classes That Compose Terrestrial Environmental Sensitivity Index



Note. Adapted from “Sensitivity Mmapping of Oil Pollution Incidents in Land Environments,” by P. T. de A. Martins, P. S. Riedel, and J. C. de C. Milanelli, 2018. Acta Scientiarum. Technology, 40(1), Article 30219 (https://doi.org/10.4025/actascitechnol.v40i1.30219).

Figure 2

Relative Sensitivity Attributed to Each Class of Variables of Terrestrial Environmental Sensitivity Index, Graphic Analysis and Corresponding Index



Note. Adapted from “Sensitivity Mapping of Oil Pollution Incidents in Land Environments,” by P. T. de A. Martins, P. S. Riedel, and J. C. de C. Milanelli, 2018, *Acta Scientiarum. Technology*, *40*(1), Article 30219 (https://doi.org/10.4025/actascitechnol.v40i1.30219).

Martins et al. (2018) reiterated the need to note that all classes have the same environmental importance and are equal in value. So, suppose there are two high sensitivity classes, one intermediate and two low. In that case, the final sensitivity will always be the same, regardless of the combinations of partial variables that make them. Another thing worth highlighting is that the rate five is derived from three possible combinations after arranging them according to the NOAA index system (shown as numbers 9, 10, and 11). Thus, there are a correlation between the followings: (1) composites lacking high partial sensitivity to low sensitivity, (2) composites with one or two high partial sensitivities to intermediate final sensitivity, and (3) composites with three or more high partial sensitivities to high absolute sensitivity (Figure 2). Then we can simplify NOAA ESI sensitivity (from 1 to 10) as follows; indexes 1 and 2, is 1 (very low), indexes 3, 4, 5 and 6 is 2 (low), index 7 is 3 (intermediate), index 8 is 4 (high) and indexes 9 and 10 is 5 (very high) (IPIECA et al., 2012).

Step 2: Ranking of the Sensitive Ecosystems (Biological) and Natural Resources

Here, one may rank the sensitivity of resources base on their recovery time after a spill. IPIECA et al. (2012) enumerates various existing classifications for ranking biological and natural resources sensitivity: the International Union for Conservation of Nature (IUCN) Red List (conservation status and distribution information on endangered species), lists of rare, endangered, and threatened species and habitats, etc. In all, there is a need to consider the likelihood of impact. IPIECA et al. (2012) also mentioned that managed areas might be part of sensitivity ranking, such as, low to medium sensitivity for local protection status, medium for national status, and high for international status. Perhaps various sensitive species exist in the same area, the highest sensitivity is maintained. To account for diversity may require a simple matrix (Figure 3) to consider it as one, or each area separately, the species' sensitivity, and the diversity to assign an overall sensitivity ranking to the area.

Figure 3

Diversity of Sensitive Species (on the Same Area)

Sensitivity of species (Highest)	Very Low	Low	Intermediate	High	Very High
Very Low	Very High	Very High	Very High	Very High	Very High
High	High	High	High	High	Very High
Intermediate	Intermediate	Intermediate	Intermediate	High	High
Low	Low	Low	Intermediate	Intermediate	Intermediate
Very Low	Very Low	Low	Low	Low	Intermediate

Diversity of sensitive species (on the same area)

Step 3: Ranking of the Socioeconomic Resources

One could adopt a similar approach for the sensitive biological resources in ranking the sensitive areas of human use and activities that could be affected directly or indirectly by a spill. According to IPIECA et al. (2012), there are parameters available for consideration when ranking socio-economic resources and features: the importance of the activity, the number of personnel employed, the revenue, even the duration of interruption for various degrees of pollution. Another factor is the number of different activities on the same area of the coast (terrestrial) to develop a similar matrix for sensitive biological resources.

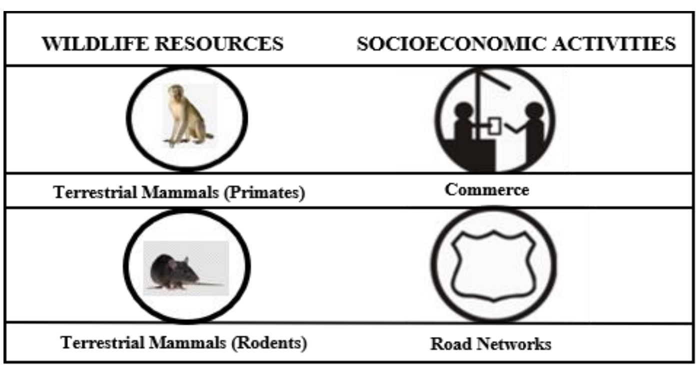
Additional Factors

In Big Bend Country, the Texas region that houses Permian Basin occupies the extreme western part of the state eastward, generally to the Pecos River. This region comprises diverse habitats and vegetation, varying from the desert valleys and plateaus to wooded mountain slopes. Mountain outwash materials have formed the soils of the Big Bend. Surface textures and profile characteristics are varied. Soil reaction is generally alkaline. Due to the diversity of soils and elevations, many vegetation types exist in the region (TPWD, n.d.). There is a tendency to practically use the data collection and the representation of biological resources and socio-economic activities, adopting the NOAA criteria for the environments, where the highlighted groups are specific to the study area.

However, the symbols representing species and land use properly in terrestrial environments may not be a good representation in a coastal area. Examples are terrestrial mammals (primates, rodents, and others), several kinds of birds, agricultural and animal husbandry, municipal water and wastewater facility or commerce, road administration services, and areas common to the road (Figure 4). Meanwhile, in coastal mapping environments, the only existing relationship is between the biologically sensitive resources and fauna such as nesting sites, breeding, nursery, and feeding areas. And since the representation of vegetation is naturally by ESI, then they are both close correlated factors (Martins et al., 2018).

Figure 4

Representative Groups of Fauna and Activities



Land use and land cover mapping are considered essential parts of the TESI composition and crucial in oil spill events in terrestrial environments (Martins et al., 2018). According to Ozigis et al. (2018), there is a high tendency of oil reaching the biological and socioeconomic components through runoff and atmospheric inputs (National Research Council, 2003) by ingesting toxic compounds through the biota's respiratory structures, coating, and smothering, affecting temperature adaptation, gas regulation, and other life-supporting processes, depending on the type of land cover.

The biota's oil spill impact is less likely in areas with established artificial land cover (including urban and other regions). At the same time, the socioeconomic environment is the most impacting factor. Invariably, the Oil spill will undoubtedly impact the biota in forest/woods areas. Therefore, one may achieve the land cover item's adequacy to the map of environmental sensitivity to the oil in two ways. The first is through the availability of a land cover map append to the sensitivity map; second, land cover as an auxiliary index connected to TESI.

The proposed ranking of an auxiliary index attributes the first four letters of the alphabet A, B, C, and D to areas without land covers, such as those representing rocky outcrops and artificial areas; the intermediary two letters E and F represent areas with low land cover density and under human management and cultivation, such as areas with herbaceous, shrubby and agricultural cover; the last three letters G, H. and I represent areas of dense vegetation, such as woods and forests (Table 4).

Table 4

Auxiliary Index Ranking

Auxiliary index	Land cover
A	Rocky areas/outcrops
B	Bare soil (soil or sand that does not cover by grass)
C	Established artificial (impervious areas, covered with concrete or gravel)
D	Established artificial (sport and leisure facilities with artificial lawn)

E	Agriculture
F	Herbaceous plants/shrubby vegetation
G	Silvan (wooded)
H	Mixed woodlands
I	Forest/woods

Therefore, an area with TESI 7 plus forest/woods land cover make up class 7I. Cartographically, the auxiliary index adopts the usage of hatching to ensure the TESI and land cover's simultaneous visualization. As mentioned above, land cover representation is efficient since it includes the two indexes within the same area and scale. However, there is a need to continually update this kind of information to avoid low-quality map because the map's quality may be somewhat impacted negatively by the small size of some land cover polygons and the amount of data needed for a map's composition.

In the past, the development of ESI maps was through drawing directly onto paper maps (IPIECA et al., 2012). There is vast advancement in technologies now, with numerous graphics and drawing software. Specific ones for spatial data, such as MapInfo, Surfer, Global Mapper, AutoCAD Map 3D, and Environmental Systems Research Institute (ESRI) - Geographic Information Systems (GIS), all are acceptable and widely used in local and national administrations and by the industry. For this study's purpose, Geographic Information Systems (GIS) of ESRI would be employed for its great to undertake land use analysis.

However, IPIECA et al. (2012) recommended taking note of the application technicality because the capacity required to undertake each step varies and is an essential consideration in processing method selection. These considerations should include whether the method involves using GIS and the availability of the appropriate software and licenses (e.g., ArcGIS advance or standard). Also, to ensure the availability of GIS users with required skill sets, including awareness of the rudiments, benefits, and balancing that, has to do with dealing with raster versus vector data efficiently. And there is a need to consider the computational system's processing limitations since sensitivity mapping may require the processing of multiple and detailed datasets.

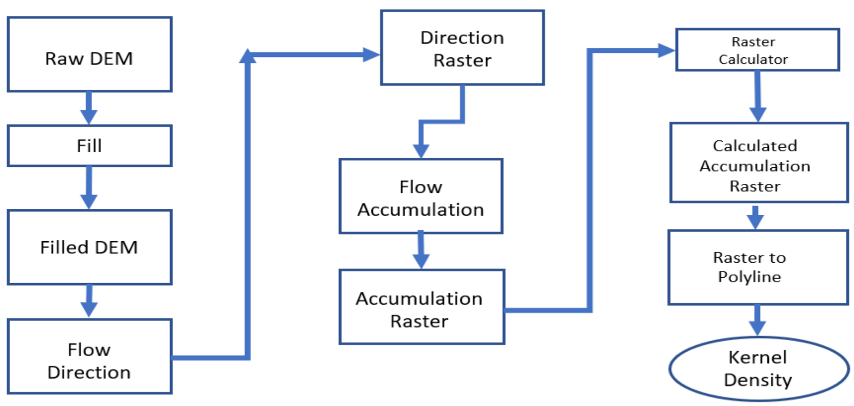
This pilot study will employ 2001 topographic maps of USDA-NRCS-NCGC Digital Raster Graphic County Mosaic of Midland County (1:24,000). A 2011 National Land Cover Dataset (NLCD) and scanned image of a USGS standard series topographic map with all collar information (e.g., legend, scale bar, index map, etc.). This map would be vectored and reproduce the shaded relief images within the Geographic Information System (GIS), where all the stages to produce ESI Maps occurred. The Soil Survey Geographic (SSURGO) database by U.S. Department of Agriculture, Natural Resources Conservation Service will be used for the identification of the soil types in the areas.

This study would also define TESI's environmental segments by identifying the land's homogeneous zones using the physiographic compartment technique and employing Soares, and Fiori's (1976) proposed logic and systematic interpretation of aerial photography. It would also employ the free, high resolution, orthorectified, and mosaicked satellite imagery provided by Google Earth, with 6 meters spatial resolution and dated 2020. Relief features, analyzed and used for the delimitation of homogeneous zones, were based on Solín (2005); with these details, this study would establish a database in GIS, where polygons, corresponding to the several compartments, would be named according to the classification of key variables, and constituting an environmental segment.

Employing a couple of hydrology tools and a raster calculator of the spatial analyst in Arc-Toolbox, the drainage network would be identified and vectored from aerial images, aided by shaded relief images to generate drainage density with the kernel density tool, all in ArcGIS (Figure 5). And due to close co-relationship with permeability, the density class intervals would be co-related to relative permeability and grouped based on the intervals shown in Figure 2. This study would add calculations of rates for the high-density class within each environmental segment to the database.

Figure 5

Drainage Density Delineation Workflow



Slope rate, on the other hand, would be based on topographic maps considering the following intervals: high (> 30%); intermediate (15-30%); low (< 15%), and this study would add these intervals to the database after applying the geoprocessing zonal statistic tool of the spatial analyst.

This study would determine the soil texture by analyzing the embankment type confirmed by granulometry details of the study areas' soil types. Then tabulate the granulometry rates and grouped them into three classes, following the classification in

Figure 2. In turn, these data become a factor in the environmental segments' spatial database.

The analysis of the segments concerning soil, slope, and embankment type would be adopted in profiling the soil thicknesses as provided by the measurement of the thickness of the alteration profile within the compartments in the study areas. The exposed profiles along the road and the river embankments could of use in this measurement. The classes would also include the intervals, as highlighted in Figure 2.

The next variable is the water level - the water depth, which could also be called the water table (WT). The thickness of the unsaturated zone could estimate the WT, which varies from zero (where groundwater reaches surface water) to more than 100 m (in some deserts) (Dodds, 2002). Also, estimating the WT could use topographic maps, aerial photos, fieldwork observations (if available), and well-water levels report of the Texas Water Development Board (TWDB, 2019), and real-time water level data of Groundwater for Texas (USGS, 2021). Based on intervals provided in Figure 2, the variable's classes can be defined and included in the database, associating predominance to the homologous zone.

The study would assign the partial environmental sensitivity (low, intermediate, and high) to each class to establish the classes for all the key variables and incorporate all the associated information into the database. As shown in figure 2, graph analysis would define the environmental segment's final TESI.

Martins et al. (2018) recommended identifying the study areas' socio-economic activities through fieldwork. Simultaneously, the geographical coordinates, photographs, and descriptions of all the buffered infrastructures and events should be determined and registered. A bibliography can provide a fauna survey according to Johnson et al. (1997) in the Biology of the Rio Grande border region. The species' spatial locations, the plant's appearances (physiognomy), and photograph details would be gathered and push into the ArcGIS database. These details would be represented cartographically with harmonized symbols following NOAA standards (IPIECA et al., 2012). The mapping of the land cover would be by visual interpretation of aerial photos with the aid of interpretation tools described by Jensen (2009), coupled with fieldwork when deemed necessary.

The commission currently has a reporting step on the Oil and Gas Accident Reporting page of their website with the toll-free and local number to call to report an environmental emergency, discharge, spill, air release from oil and gas facilities. After which, a follow-up letter shall be submitted to the district office giving the full description of the event, including, but not limited to, the volume of crude oil, gas, geothermal resources, other well liquids, or associated products that are lost. Also, there is a Public GIS Viewer digital map. A GIS interface gives users the ability to view oil, gas, pipeline, and other associated data in a map view, guiding the field crew and emergency team to the oil spill location. There is no detail on the resources' ranking and sensitivity even though the map has aerial photographs to provide a current pictorial view of the ground that no map can equal.

Background and Context

The Texas Railroad Commission has been historically one of the most important regulatory bodies in the country. It has a strong influence on the supply and price of oil and natural gas throughout the United States for much of the twentieth century. As its name implies, State initially established the commission to oversee railroads. The

Railroad Commission, in its inception, had massive success in restraining intrastate freight rates (Prindle, 1995). In 1917 the legislature granted the commission the authority to ensure that petroleum pipelines remained the common carriers, that is, no refusal to transport anyone's oil or gas. Two years later, the commission received responsibility for publicizing well-spacing rules. In the early 1920s, the agency accepted jurisdiction over gas utilities.

This gradually growing responsibility prepared the enormous expansion of commission activity during the next decade (Prindle, 1995). The Railroad Commission was, until the early 1970s of vital importance to national and international energy supply. But with the decline of Texas oil reserves, the significant increase in world demand, and OPEC's rise, the commission's influence over oil dwindled. Its responsibilities in this area consist mainly of enforcing and maintaining regulations on Oil and Gas, Transportation-Gas Utilities, Surface Mining and Reclamation, and Liquefied Petroleum Gas divisions. Monitoring and inspection of oil and gas operations are the responsibility of the Oil and Gas Division.

So, being the body saddled with the responsibility to oversee oil extraction and enforcing cleanliness in the land fields, there is a need for TESI tailored after the NOAA standard in marine and coastal environments that is currently unavailable. No doubt, there could be other plans to deploy in case of an emergency oil spill but not a TESI map that can provide a concise summary of terrestrial resources that could be at risk in the event of an oil spill and aid a quick response.

My background is in geology with experience in environmental management and remediation, and I was involved in several oil spillage cleanups nationally and internationally. In addition, I am currently managing the geospatial and asset information for a conventional oil-producing company in Texas, conversant with the RRC database and operations. As a user of RRC public data, without any bias, findings show that there is no similar version of NOAA Marine and coastal ESI developed for the terrestrial environment, which could earn the commission a big win.

When RRC was contacted with the idea of research, consenting to this was a huge motivation. But the commission communicated immediately that the agency would not partner or sponsor the research due to legal limitations. Still, the commission emphasized that they collect a tremendous amount of data related to those industries they oversee as a regulator. All these data are public and accessible to public members, and that they are willing to provide more information that may benefit this effort.

Summary

According to IPIECA et al. (2012), differentiating the relative sensitivity and importance of various assets by area requires proper identification, prioritization, and ranking of the sensitive assets. The reason is that several natural assets may hold different social and economic values either at the local or national level. Even though there is no particular method recommended for locating and prioritizing sensitive areas and assets, it is not prudent to solely adopt automated and computer-aided practices without stakeholder consultation (IPIECA et al., 2012). Adopting a map-based perspective is easily understood and widely used by decision-makers (IPIECA et al., 2012).

When a sensitivity map is well planned and composed, it provides several benefits, such as visual representation of the threatened and at-risk assets. This map helps planners and decision-makers understand the resources' location and protection urgency

(NEA & UNEP-WCMC, 2019) in the event of accidental oil discharge. It aids the development of protected area networks to protect high biodiversity areas (Levin et al., 2015). In their spatial planning, the government and private sector could also benefit from this map, being informed at the project level, to ascertain activities and developments in areas where their associated negative pressures will have the most negligible effect on the environment or society.

Prevention, mitigation, preparedness, operations, relief, recovery, and integration of the knowledge gathered are imperative in all impact management phases. Improvement in the effectiveness of response operations to minimize negative impacts caused by accidental events could result from the picked-out response strategies (Jensen et al., 1990). e.g., several environmental assets could be more sensitive to the oil spill's negative impacts than others (Carey et al., 2014). and with the aid of sensitivity mapping, responders and decision-makers can easily prioritize operations to protect areas most susceptible and vulnerable to oil's adverse effects (IPIECA et al., 2012). All these benefits are also applicable to the terrestrial version of sensitivity mapping.

In Section 2, this study would explore a data collection process and analysis. This step includes a systematic process of gathering observations or information to gain first-hand knowledge and original insights into the research problem, a series of actions or steps to be performed on data to verify, organize, transform, integrate, and extract data in an appropriate output format for further usage. It will also involve actions and methods performed on data that help describe facts, detect patterns, develop explanations, and test hypotheses.

Section 3: Data Collection Process and Analysis

Introduction

RRC of Texas is the oldest regulatory agency with a primary focus on the oil and gas industry, regulating the exploration, production, and transportation of oil and natural gas within the state (RRC, n.d.). It is also saddled with responsibilities such as preventing the waste of the state's natural resources and pollution, protecting the correlative rights of different interest owners, and providing safety regarding hydrogen sulfide (RRC, n.d.)

The state of Texas houses approximately 466,623 miles of pipelines transporting hazardous liquids, natural gas, and petroleum throughout the state. Simultaneously, large industrial tankers transport oil, gas, and other fuels on the road (Worland, 2019). These petrochemical transportation methods could easily fail, causing horrific disasters that could destroy the environment and cause injuries or even deaths to oil workers and residents due to delay in response time. Oil spills onto land are becoming relatively common across the globe due to prospecting, extraction, and oil transportation, which often result in accidental oil spills or pipeline leakage.

RRC, the state-recognized regulatory agency, does not seem to have a similar plan to coastal and marine environments to respond to potential terrestrial emergencies. The vulnerability of the land and terrestrial habitats to oil spills could be harmful, possible damage to biological resources, cultural and economic objects, and nature conservation territories. In this regard, developing plans for addressing potential terrestrial environmental disasters using the GIS is deemed necessary and incredibly urgent. These plans, if developed into GIS tools—a sensitivity map that represents how sensitive land is to oil, ranked by the ESI (Berenshtein et al., 2019)— would become an element to guide disaster contingency planning.

Road and pipeline networks are the primary vectors in accidents that cause oil spills in the land environment. Initially, NOAA conceived the oil spill ESI map for coastal and marine environments, later extending it into other aquatic environments such as rivers, lakes, and swamps (NOAA, 1995). There was never a prior consideration for land environments that might be polluted by oil spill events (Martins et al., 2018).

This qualitative study explored and used publicly available and nonproprietary data to mimic the coastal and marine sensitivity representations on emergency preparedness for environmental disaster in terrestrial settings and produce a plan for RRC to address such potential disaster. One proposed long-term solution is to develop this plan into a TESI map, a GIS tool to classify the resources based on the sensitivity and relative significance of environmental and cultural assets in the region (Steadman et al., 2004). This study may contribute to the efficacy and design of such a product for RRC.

Study Area

Theoretical and practical characteristics combined were considered for the ESI map plans and applied to Andrew Highway in Texas's Midland city. Pilot areas were defined on Interstate 20 (Texas I-20) at the intersection of North Midkiff Road and the FM 1788, a few miles before the Midland County line in Midland city. Around it was buffered polygons of 500m created. Midland city, otherwise known as the "Tall City" because of the impressive downtown buildings that can be seen for miles on the horizon when approaching the town, is Midland County's County seat. The town location is on Interstate Highway 20; U.S. Highway 80; State Highways 158, 191, and 349; the

Missouri Pacific Railroad; and numerous county and local roads, 20 miles northeast of Odessa and 39 miles southwest of Big Spring in the north-central part of the county at 32°00' north latitude and 102°10' west latitude. The elevation is 2,779 feet.

According to Leffler (2021), the boom in oil and gas production in the Permian Basin has rapidly expanded over the years, especially between 1945 and 1960; Midland development took a massive shift from being a small country town to a city with a skyline. Around 1950, this development prompted about 215 oil companies to have offices in Midland, with the city's population increasing to 21,713. By 1960, the population was 62,625 (Leffler, 2021). In 1990, Midland had a population of 89,443, with 106,611 in the metropolitan area. Though Midland has endured many economic slumps over the years, the city has remained the financial and administrative center for the Permian Basin. Oil, chemicals, and plastics have also been crucial to the local economy. The ranchers and farmers in the surrounding area rely on Midland for their supplies and shipping.

Data, Process, and Analysis

If an oil spill occurs, ESI maps initially summarize nearby coastal resources at risk. Examples of at-risk resources include biological resources (e.g., birds), sensitive shorelines (e.g., marshes and tidal flats), and human-use resources (e.g., public beaches and parks; NEA & UNEP-WCMC, 2019). This idea was translated and adapted for a terrestrial environment with consideration to biological resources, socioeconomic resources, and the proposed sensitive variables that control oil dynamics in terrestrial environments (slope, soil texture, soil depth, water table depth, and drainage density).

Materials and Data Collection Methods

Nearly all of the data were from government agency and open-source data warehouses found on the internet. The main raster-based products, topographic maps, and land cover were downloaded from Natural Resources Conservation Service's geospatial data gateway, and aerial photos came from ESRI and Google. The vector data, such as roads, were digitized from aerial photos and buffered to about 500 meters. Apart from the spatial data, there were nonspatial data required for the study, well-water levels reports, and real-time water level data on groundwater to establish water depths. Some of these data were downloaded and transformed from vector to raster data and vice versa as deemed necessary. It was ensured that the raster data were in the desired format for the process.

Data Management

The ESI data structure design was in GIS format, because of its capability of handling complex relational links between spatial and nonspatial data. The collection, processing, and creation of data adhered to Federal Geographic Data Committee (FGDC) standards. This study ensured that the metadata successfully fulfilled these requirements. Metadata consist of a catalog record of who created the data and the recommended usage of the data, including the data's limitations, data creation date, and other vital information about the data. The last part of the metadata that was important was the data's location.

With a robust and scalable GIS database that housed the data as mentioned above, differentiating the relative sensitivity and importance of various assets by area with proper identification, prioritization, and ranking of the sensitive assets was made easy (IPIECA et al., 2012). This resulted in a well-planned and composed sensitivity map with the benefits of visual representation of the threatened and at-risk assets that aided in the development of a better understanding of the resources' location and protection urgency (NEA & UNEP-WCMC, 2019). It also encouraged the further development of protected area networks to watch high-biodiversity areas (Levin et al., 2015).

The research used the following databases (2011-2021): EBSCO, Taylor & Francis, and Thoreau. Key terms searched were *environmental*, *sensitivity*, *index map*, *socioeconomic*, *prospecting*, *extraction*, *oil transportation*, *LiDAR*, *GIS*, and *spatial analysis*. The following related research topics were used to gain historical context: ESI, coastal and socioeconomic resources, oil spill modeling, and environmental monitoring in pollution science.

The research used ArcGIS mapping software of ESRI to integrate maps of the region with geographically referenced biological resources, human-use resources, and TESI-classified terrestrial ranks based on their sensitivity to oiling. The map contains various associated shapefiles with attributes summarized in detail that enable queries to the GIS data and served as a quick reference for oil spill responders and terrestrial zone managers.

The study analyzed each geographic information layer to define its accuracy, interest, and limits and assess the requirements to complete the data or improve their accuracy. Each was accompanied by information on the geographic data (i.e., metadata), including the owner, nature of the spatial data (vector/raster), year of production, method of creation of the data, scale of digitization, and sources.

Summary

While the mapping of the environment’s sensitivity to an accidental oil spill is an essential step in oil spill preparedness, the map requires determining which data assets to include and which method to use. In this regard, thought should be given to whether the focus should be on socioeconomic and biological or environmental assets, with succeeding recategorization approaches based on the study’s goal (i.e., the weighting of assets to evaluate potential trade-offs).

Understanding the realm and assessing the dynamic variables are essential, given the potential specificity of characteristics of different domains, such as water table, soil thickness, slope, drainage density, and so forth. This awareness is vital due to varying factors of pressures in different environments. For instance, in a steep slopes area, soil holds very little oil (Etkin et al., 2007), in contrast to a similar-sized spill on land that has a gentle slope. Based on these facts, various methods may be employed to account for differences in realms with multiple environmental data requirements. This study explains how oil can behave and the sensitivity of the terrestrial environment surrounding the roads and pipelines.

In Section 4, I present an evaluation and recommendations on the processes involved and the highlights of the harmonized approach for oil spill sensitivity mapping that showcase the fact that the ESI methodology is efficient in the terrestrial environment.

Section 4: Evaluation and Recommendations

Introduction

As West Texas prevails as an oil exploration and extraction colony, the problem is that prospecting, extraction, and oil transportation often result in an accidental oil discharge or pipeline leakage. ESI mapping is an approach widely used in coastal and marine environments globally. After the Deepwater Horizon oil spill of 2010, ESI gained more popularity (Nixon et al., 2016; Sealey & Patus, 2015). RRC, as the state regulatory agency, does not seem to have a similar plan to respond to these types of potential emergencies on land. Meanwhile, the vulnerability description of the land and terrestrial habitats to oil spills could have negative consequences, possible damage to biological resources, cultural and economic objects, and nature conservation territories, should an oil spill occur.

Thus, developing plans for tackling potential terrestrial environmental disasters using the GIS is deemed necessary and incredibly urgent. This plan, if rolled into GIS tools—a sensitivity index map—would help in oil spill response (OSR) activities and minimize oil spills' potential damage to natural and human-made environments (Shavykin & Karnatov, 2018). Sensitivity maps highlight in ranks how sensitive the land and shoreline are to oil using the ESI (Berenshtein et al., 2019).

According to Martins et al. (2018), there was no prior consideration for land environments that oil spill events might pollute. The evidence toward this current bias is the consolidation of methodologies oriented to elaborate oil spill ESI maps for aquatic environments. In contrast, those directed toward the terrestrial environments are rarely analyzed (Martins et al., 2018).

This study was approved by the Institutional Review Board (IRB) of Walden University with approval number 05-20-21-0922218.

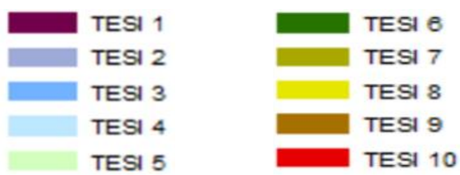
Findings and Implications

The application of physiographic compartments to the study area would provide the numbers of the environmental segments that can be afterward divided into pilot areas depending on how long the study area is. Additionally, the number of segments in a pilot area could vary. Then, the final TESI of the segments of the pilot areas, with their respective classes and partial sensitivities, can be synthesized, ranging from TESI 1 to TESI 10, with TESI 10 being the most sensitive and TESI 1 the least sensitive. These 10 TESI levels could be color-coded from cool to warm colors, indicating increased sensitivity, as shown in Figure 6.

Each color corresponds to a particular type of segment, giving identification of the kind and relative sensitivity immediately. For example, a segment in a pilot area with a high slope, fine soil texture, very thick soil, deep water table, and intermediate permeability would be TESI 1; in contrast, a segment in a pilot area with low slope, coarse soil texture, little thick soil, shallow water table, and high permeability would be TESI 10.

Figure 6

Terrestrial Environmental Sensitivity Index



The planner can identify these segments through various sources: existing topographic or thematic maps and studies; local knowledge; and remote sensing technologies such as low altitude overflights, aerial photos, and satellite imagery of high resolution. However, when using remote sensing data, a truthing ground mission is essential to validate the data and undertake surveys where data are missing. The TESI used to categorize various segment types, as highlighted above, should not be confused with the TESI mapping methodology used to define the overall sensitivity of the land, considering the TESI and the sensitive biological, human-use, and socioeconomic resources.

Mapping the Sensitive Elements of the Areas

When mapping the general environmental sensitivity of the land and terrestrial ecosystems, there is a need to map both the protected areas and areas of biodiversity importance, including the land and coastal species, habitats, and natural resources that could be affected by accidental oil pollution. The TESI scale of 1 to 10 mentioned above does not address the broader context of the oil spill. In particular, this must include the following:

- protected areas and important areas of biodiversity,
- different types of land and coastal habitats/ecosystems, and
- endangered species (can be identified using the IUCN Red List [IUCN Red List, 2021])

It is crucial to understand and map the location of regionally recognized and designated sites to identify sensitive ecosystems, critical habitats, and endangered species. The planner can access these data sets via the USGS Protected Areas Database of the United

States (PAD-US). The USGS PAD-US is the official GIS-based national inventory of protected area boundaries within the United States. It includes public lands and parks, Wilderness Areas, National Wildlife Refuges, reserves, conservation easements, Marine Protected Areas, and more.

Endangered sensitive species may include the following:

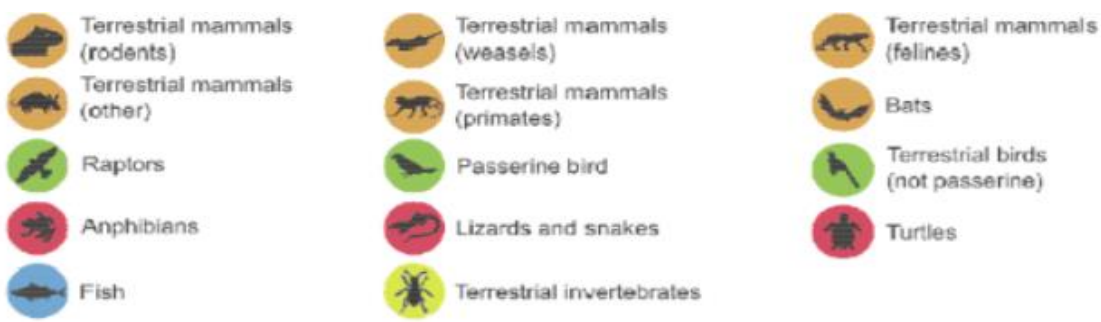
- birds (e.g., turkeys, quails, partridges)
- rodents (e.g., bats, mice)
- terrestrial mammals (which may be affected by contact with oil or by feeding on contaminated species, e.g., weasels, felines, primates, and others)
- fish (nursery areas, long fish, lobe-finned fishes, etc.)
- terrestrial invertebrates (crustaceans, lobsters, shrimp, endangered insects, etc.)
- reptiles/amphibians associated with land (turtles, alligators, frogs, lizards, snakes, etc.).

It is also necessary to have adequate scientific support to select the specific species to map and to understand their vulnerability to an oil spill. These vary both spatially and temporally. The species of particular concern (IUCN Red List, 2021) for being sensitive to oil must be located, precisely where pollution could affect these specific fragile and limited populations (IPIECA et al., 2012).

Figure 7 shows some of the biological resources and their respective symbols following NOAA standards, as highlighted by IPIECA et al. (2012). In mapping these biological resources, it is also necessary to consider seasonality and life stages (i.e., breeding, spawning, hatching, migration, etc.). Depending on the detail of information available, the species concentration information can be simple (presence/absence) or more detailed (1: no data, 2: rare, 3: common, 4: abundant, and 5: highly abundant). Presenting this information here is just a preference. The use of the four seasons (i.e., spring, summer, autumn, and winter) should be avoided to prevent confusion between the northern and southern hemispheres.

Figure 7

Biological Resources



Note. Adapted from *"Sensitivity Mapping for Oil Spill Response*," by International Petroleum Industry Environmental Conservation Association, International Maritime Organization, and International Association of Oil & Gas Producers, 2012 (https://www.ipieca.org/resources/good-practice/sensitivity-mapping-for-oil-spill-response/).

Mapping the Sensitive Socioeconomic Features

Sensitive socioeconomic features to be mapped should include nonliving resources that may be directly injured by oiling; managed areas that may suffer economically (e.g., through interruption of use if oiled); and areas that may be valuable in a spill for spill access or staging activities. These features can be grouped into various categories:

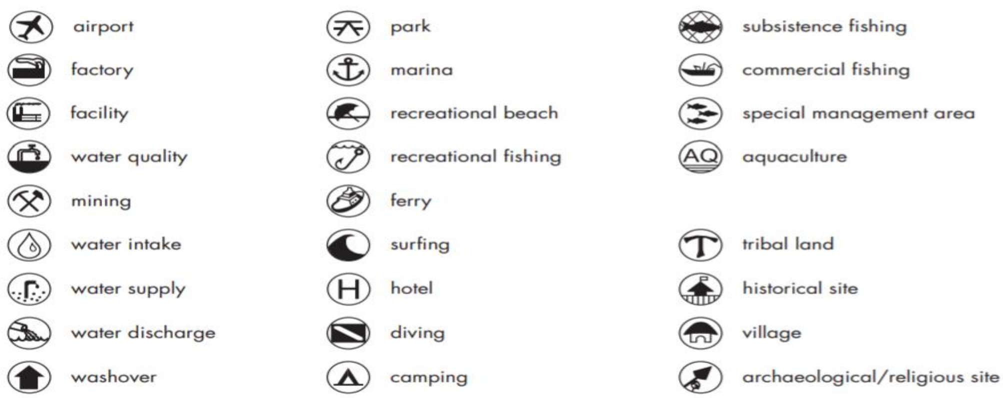
- subsistence, artisanal and commercial fishing, and fishing villages;
- aquaculture;
- water intakes (industrial use);
- tourism and recreation areas (hotels, restaurants, marinas, beaches, recreational fishing, diving, etc.);
- port (including activities and infrastructures);
- industrial activities (relying on maritime transport);
- infrastructures related to oil exploration, production, and transport activities; and
- cultural sites (archaeological, historical, religious, etc.).

In mapping socioeconomic features, the objective is not to identify all hotels, restaurants, or factories comprehensively but to locate the activities and the areas that have the potential to suffer the most significant impact. The mapping project coordinator should define the socioeconomic features to consider before the development of the maps. The relative importance of these features and the need to protect them in a spill need to be confirmed with local or regional policymakers. It is important to note that socioeconomic features may also be subject to high seasonal variation (e.g., tourist season, fishing season, aquaculture season, etc.). If possible, seasonal information should be mapped and presented as additional information accompanying the maps.

Figure 8 contains a list of some of the socioeconomic features and their respective symbols, following NOAA standards as highlighted by IPIECA et al. (2012).

Figure 8

Symbols for the Mapping of Sensitive Human Use and Activities



Note. Adapted from *"Sensitivity Mapping for Oil Spill Response*," by International Petroleum Industry Environmental Conservation Association, International Maritime Organization, and International Association of Oil & Gas Producers, 2012 (https://www.ipieca.org/resources/good-practice/sensitivity-mapping-for-oil-spill-response/).

A sensitivity index proper to terrestrial environments is essential because it made possible the systematization of an index to be efficient and quick. Additionally, it helps in localizing and prioritizing the most sensitive sites and resources for decision makers in a usable and straightforward manner. Only a few sensitive areas are present on the land in rare cases, and the available response equipment may be sufficient. However, it could be that equipment available is limited in comparison to the exposed areas and it is necessary to prioritize sites and resources

- identified within the geographical area covered by the maps and
- competing within an area (e.g., fishing area, aquaculture vs. hotel and airport).

In general, the mapping of the sensitive elements of the areas would require the regulatory agency to conduct the prioritization process with the main stakeholders to discuss features and places to be protected and clean up priorities openly.

Results

The results would give a clear indication that the GIS-based TESI with classification rules for terrestrial sensitivity would provide a rapid and flexible framework for ranking of terrestrial sensitivity to oiling based on known standards. When incorporated with data on biological and human resources, this TESI would provide a complete picture of environmental sensitivity to oil spills across different environments in the region. Further, there is an indication of the potential approach in supporting the agency's response and regulatory teams. Essentially, this is an endeavor of supporting decision making for emergency response, clean-up activities, and damage evaluation, as well as supporting environmental advocacy in this oil-producing region.

Implications for Positive Social Change

TESI maps and data provide concise summaries of land resources that could be at risk in the event of an oil spill. When a spill occurs, TESI maps can help responders meet one of the primary response objectives: reducing the environmental consequences of the spill and the cleanup efforts. Additionally, response planners can use TESI maps—before a spill happens—to identify vulnerable locations, establish protection priorities, and identify cleanup strategies.

The purposes of mapping are to assess the feasibility, financial implications, and consequences of alternative courses of action. A particular course of action is chosen by comparing its probable implications and consequences with possible alternatives. Hence, the prediction of consequences is a critical part of planning, and this prediction is precisely the aim of environmental sensitivity mapping. To predict the ecological impacts of a potential development requires projection of the following:

- the specific dangers that it will impose on the environment concerned,
- other dangers that may also be present,
- the immediate environmental responses to these dangers, and
- the longer term responses and the overall potential consequences.

Martin et al. (2012) stated that if an environmental sensitivity map is expressed in a useable and friendly form, it will be an invaluable aid in planning, with a specific response tailored to the ecosystem that could be affected, enhancing the protection of human health and restoring usability to the spill site as quickly as possible. Since the urban areas comprise everything from paved surfaces to forests and parks, environmental consequences can include potential ecosystem destruction. Rendering the entire habitats functionally unable to support the species present; biodiversity is reduced in this process when existing organisms in the habitat are displaced or destroyed. Some very practical hazard-prevention measures, such as preventing water absorption by the soil when spills occur in agricultural locations or grasslands, have the effect of choking off plant life.

In the event of an accidental oil discharge, having a plan ready will help with the highest response priorities, preventing human life impacts, avoiding oil leaching into groundwater or entering waterways as runoff, and returning the environment to productive use as quickly as possible. TESI maps enable the field planning personnel to assess the potential impacts of any proposed development and make rapid and rational choices from the environmental point of view.

According to Roberts (2019), TESI maps in general are essential decision-support tools and a crucial source of information to help responders with their decisions before, during, and after an incident. The final choice lies in the responder's responsibility to consider all relevant factors and provide the most effective spill response.

Recommendations

For a regional oil spill contingency plan, the commission's department in charge of oil spill preparedness and emergency response will be responsible for managing the sensitivity mapping project. This includes disseminating the final products to the main stakeholders involved in oil spill preparedness and response and those accountable for updates to the atlas. In all cases, the development of the maps and the identification and prioritization of the most sensitive sites should be integrated into the contingency planning process and support the development of the oil spill contingency plan.

It is necessary to set clear objectives to focus the scope, the geographic coverage, and the content of the sensitivity maps. The maps to be produced must be clearly defined as decision support tools. The commission must integrate the maps into the preparedness and response system of the state or the organization. A lack of clear objectives and planning will result in unfocused, lengthy, and costly data collection and potential (re-) production of existing data sets. Additionally, the commission should decide on the format and what type of GIS will be used.

Designing and developing a plan to address a potential terrestrial environmental disaster using GIS studies offers a good layout for a TESI map. This TESI would aid in the use of quick response strategies to address real-life oil spill situations in field conditions. I recommend that if the commission ever turns this plan into a tool, there is a need to stay on the limitations that might be likely to surface. The most likely and significant hurdles could be getting funding approved and organizing staff, obtaining resources to try out this plan as a tool, and developing an excellent strategy to keep updating the database of sensitive elements and protected areas, especially when there is no emergency. It is a prevalent mistake that organizations never deem it economical to try out such a plan as a tool.

Conclusion

TESI maps are an essential tool to develop the best-suited oil spill response strategies. A sensitivity mapping tailored after terrestrial environments made possible the systematization of an index described in the plan to be efficient, quick, and simple to produce. Considering the various land cover and land types, and more importantly, the most sensitive terrestrial sites and the resources that could be affected, the oil spill sensitivity maps would guarantee fast and effective oil spill response operations. Agency must underscore that highlighted plans are a technical document that must be applied by multidisciplinary teams comprising professionals specialized in the physical environment, biological, and socioeconomic aspects. Also, due to the thematic nature of this plan, responders should know how to interpret it and be competent in its usage and application. Information and interpretations help and contribute to the authorities, who are primarily responsible for decision-taking and making during emergencies.

And because change is the only constant thing in life, this plan stands to be innovated and modified after the initial design as events unfold. As this plan recommends that the datasets be stored within a GIS enterprise, there is a clear opportunity to update the GIS database, thus making it possible to have updated information relevant for emergency operation and response. And with the TESI in place, new data obtained from remote sensing and fieldwork can be quickly added to the database, thereby allowing for rapid assessment of ongoing emergencies, and taking proactive measures to forestall potential hazardous events. These ideas are part of the methodological evolution and must be factored in as such. The agency must also incorporate road planning, coupled with the responsibility of road engineers and constructors. Another thing is categorizing the methodology proposed to fit TESI into three classes only (low, intermediate, and high) widely used in environmental studies.

Supplementing land cover as an annex or even an auxiliary index is a methodological possibility that the agency must consider in these circumstances. In mapping the sensitivity of terrestrial environments, the land cover must be included as another factor, such as the TESI, biological resources, or socioeconomic activities. The agency should undoubtedly fine-tune this plan, methodology, and application over time after analyzing possible inconsistencies during real situations in the event of accidents involving oil spills.

The GIS-based ES for the terrestrial environment would present an opportunity to prioritize clean-up operations, intervention measures, planning, and supporting evidence-based decisions on strategies for clean-up and containment procedures applicable for affected environments. The study would adopt the combination of the stakeholder's inputs and the NOAA standards for the terrestrial sensitivity ranking. This approach within a spatial database supported by an ES is expected to cover the oil-producing regions of the Western part of Texas.

Limitations of the Study

The basis of any research study is the data. Proper segmentation and classification of a region require recent data. Still, the available land cover data has been altered mainly due to developments over the years, imposing limitations to the strict use of classification protocols. But incorporating the use of the aerial photograph gives some headway. When classifying a sensitivity index that presents high and low vulnerability zones, alternates on each other, especially in a relatively small area, could disorientate the responders from focusing on high or low vulnerability zones. It may lead to aggravated damage and, consequently, to the inability to distinguish the most vulnerable areas from the least vulnerable ones in the whole area. For example, in a segment or region with the same vulnerability values but different distribution of polygons, the exact value of exposure can fall into rank 1 (least vulnerable) in one case and rank 10 (most susceptible) in another. This classification method is hardly applicable if the distribution of vulnerability follows one geographical direction.

IPIECA et al. (2012) recommended using object-related vulnerability maps for minor spills in coastal and marine, which can be equally mimic for terrestrial environments. These maps are prepared only for critical regions to showcase the vulnerable entities that would assist the responder's decisions in ecologically sensitive small areas, specifically for protected natural territories, oil terminals, bays with port facilities, etc. Overall, the limitations of the study were minor. The older datasets and technologies provided a clear understanding of the changes in technology and how they might have hindered the original understanding of the environment. Time was the biggest issue with this study. Time frames from when and what data was collected compared to the data collected only a few years old posed the most significant limitation.

Section 5: Dissemination Plan

Introduction

Section 4 outlined the evaluation, recommendations, and implications for positive social change for the study. In this section, I detail the dissemination plan and the potential audience, and I present a summary. I will disseminate the results of the study through a four-page executive summary (see Appendix) to the Oil & Gas Environmental Cleanup Programs—Site Remediation Manager of the Texas RRC. The executive summary will include the plan’s highlights through the qualitative study to explore, itemize, and classify the resources that society values, such as biological, socioeconomic, and cultural assets (Steadman et al., 2004) that could be affected. I will also include the plan to mimic the coastal and marine sensitivity representations on environmental disaster preparedness to present these resources in a terrestrial setting.

After the Texas RRC has reviewed the study, if its members wish to have further discussion about my recommendations, I will schedule a 30-minute session to discuss the analysis, results, and recommendations. Several agencies at all levels of government might benefit from the information presented in this study. I could share the study in training sessions, leadership conferences, and academic or research settings.

Summary

This research study highlighted the factors to be considered in designing and developing a plan for addressing potential terrestrial environmental disasters using GIS. Mimicking the coastal and marine sensitivity representations on emergency preparedness for environmental disaster in terrestrial settings produces a plan to develop the best-suited oil spill response strategies. Oil spills are becoming critical, especially in an exploration colony such as West Texas (Sanderson et al., 2019). Further, oil transportation should be of great concern because roads and pipelines have been the transportation mode of oil derivatives intensively used within an extensive and comprehensive network covering most West Texas territory (GAO, 2014).

Careful consideration and segmentation of the terrestrial environments adjacent to road and pipeline networks are regarded as essential in the plan by applying physiographic compartments technique to identify the land's homogeneous zones. And the protected areas and areas of biodiversity importance comprise land and coastal species, habitats, and natural resources that could be affected by accidental oil pollution. All of these would show where the different resources are and indicate environmentally sensitive areas.

Suppose that there is an oil transportation failure or pipeline burst that leads to accidental oil discharge. In that case, a horrific disaster could destroy the environment and cause injuries or even deaths to oil workers and residents. This plan could be rolled into the TESI map to aid in improving response time, identifying vulnerable locations, establishing protection priorities, and identifying cleanup strategies.

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Appendix: Executive Summary

As the Western part of Texas is becoming the exploration colony for the rest of the world's fuel resources. Transporting oil and its derivatives through pipelines and industrial tankers by roads would continue to be on the rise, and many communities are at risk of oil spill disasters (Chang et al., 2014). This idea prompted the need to plan terrestrially for oil spill index mapping, dedicated to deepening our understanding of oil interactions to the fragile ecosystems, the environment, and the impacts of oil on human settlements, vulnerable to spill events (Nelson, and Grubesic, 2018).

The Railroad Commission (RRC) of Texas is the oldest regulatory agency in the state. The agency saddled with the responsibilities to prevent waste of the state's natural resources, protect the correlative rights of different interest owners, prevent pollution, and provide safety in matters such as hydrogen sulfide (RRC, n. d.). Prospecting, extraction, and oil transportation are the issues that often result in an accidental discharge or pipeline leakage. And RRC being the state regulatory agency does not have a similar plan to coastal and marine environments to respond to these potential emergencies.

This qualitative study explores and uses the publicly available and non-proprietary data to establish a plan for Terrestrial Environmental Sensitivity Index (TESI) maps. A map that would provide a concise summary of terrestrial resources at risk if an oil spill occurred nearby. Additionally, to highlight plans for developing a prevention strategy to minimize damage and ensure vulnerable natural resources and local community socio-economic activities in terrestrial areas are protected.

There are two types of environments: biologically sensitive to oil and the human use of commercial, recreational, or subsistence resources that could be affected during any accidental oil discharge, depending on the area, features, and the activities nearby, various resources from what the local community utilizes as resources in terrestrial land as their main livelihood. Therefore, land use and land cover mapping greatly help in the terrestrial environmental sensitivity index composition. Land cover is a crucial element in oil spill events in terrestrial environments since the oil may reach biological and socio-economic components, depending on the type of land cover.

According to Martin et al. (2018), the biota in an area with established artificial land cover experience less impact while the socio-economic environment, on the other hand, is the most impacting factor. In contrast, the oil spill will undoubtedly impact the biota in forest/wood areas. In the map of environmental sensitivity to oil, there are two ways to adequately achieve the land cover item (Martins et al., 2018). Firstly, through the availability of a land cover map annexed to the sensitivity map; second, land cover as an auxiliary index connected to TESI.

This research utilizes the physical and geomorphic features (e.g., topography), biological characteristics, and socio-economic features such as agricultural fields categorized based on their sensitivity to the oil. There is also a usage of the relatively high spatial resolution satellite data for the planimetric detail (Jensen et al., 1990; Jensen et al., 1998). At the same time, Mapper can obtain other information needed for sensitivity maps from existing scientific publications, topographic maps, photographs, and environmental data held by organizations such as agencies, government departments, universities, conservation groups.

Also, the five critical variables that control oil dynamics in terrestrial environments, as proposed by Martins et al. (2018) was incorporated. These variables (1) slope, (2) soil texture, (3) soil depth, (4) water table depth, and (5) density of drainage enhance the development of the TESI (Martins et al. 2018). Each variable is further classified into low, intermediate, and high and attributed to a specific color. Then, defining the TESI by a set of five partial sensitivities, one for each key variable, with their respective systematization procedure and equivalent conceptual correlation.

The relative sensitivity and importance given to each specific resource at risk in this plan could differ from one region to another; assets with high priority may be considered low to medium significance in the other areas (IPIECA, IMO and OGP, 2012). Therefore, there is no recommended single method for locating and prioritizing sensitive sites and resources. Instead, the goal is to establish a general ranking for each of the three resource types included in the sensitivity maps: the variable type and its general environmental sensitivity, the sensitive ecosystems, habitats, species, vital natural resources, and the sensitive socio-economic features, in addition to stakeholder's consultation.

All this information wrap together helps highlight the areas, high potential and threatened by the oil spill in an accidental discharge. Therefore, a plan is developed for a Terrestrial Environmental Sensitivity Index (TESI) map to classify the level of sensitivities along the land and habitats of the region to protect. Terrestrial Environmental sensitivity index considers the sensitive variables that control oil dynamics in terrestrial environments (slope, soil texture, soil depth, water table depth, and drainage density), biological and socio-economical characteristics for each terrestrial environmental feature.

Spatial analysis through the geographic information system (GIS) of overlay technique is applied to determine each environmental feature to produce TESI Map. The planner can identify these segments through various sources: existing topographic or thematic maps and studies; local knowledge; and remote sensing technologies such as low altitude over-flights, aerial photos, and satellite imagery of high resolution. However, a truthing ground mission must validate the data using remote sensing data and undertake surveys where data are missing. The TESI used to categorize various segment types, as highlighted above, should not be confused with the TESI mapping methodology used to define the overall sensitivity of the land, considering the Terrestrial Environmental Sensitivity Index and the sensitive biological, human-use, and socio-economic resources.

Implementing a map-based approach is user-friendly and straightforward, decision-makers widely accept its usage. There are three simple steps involved in this methodology. First, the sensitivity information on the sensitivity map, type and sensitivity of variables, biodiversity-sensitive elements of the area, and socio-economic features would be the basis of three steps:

- Ranking of the sensitivity of the variable types
- Ranking of the sensitive ecosystems (biological) and natural resources
- Ranking of the socio-economic resources

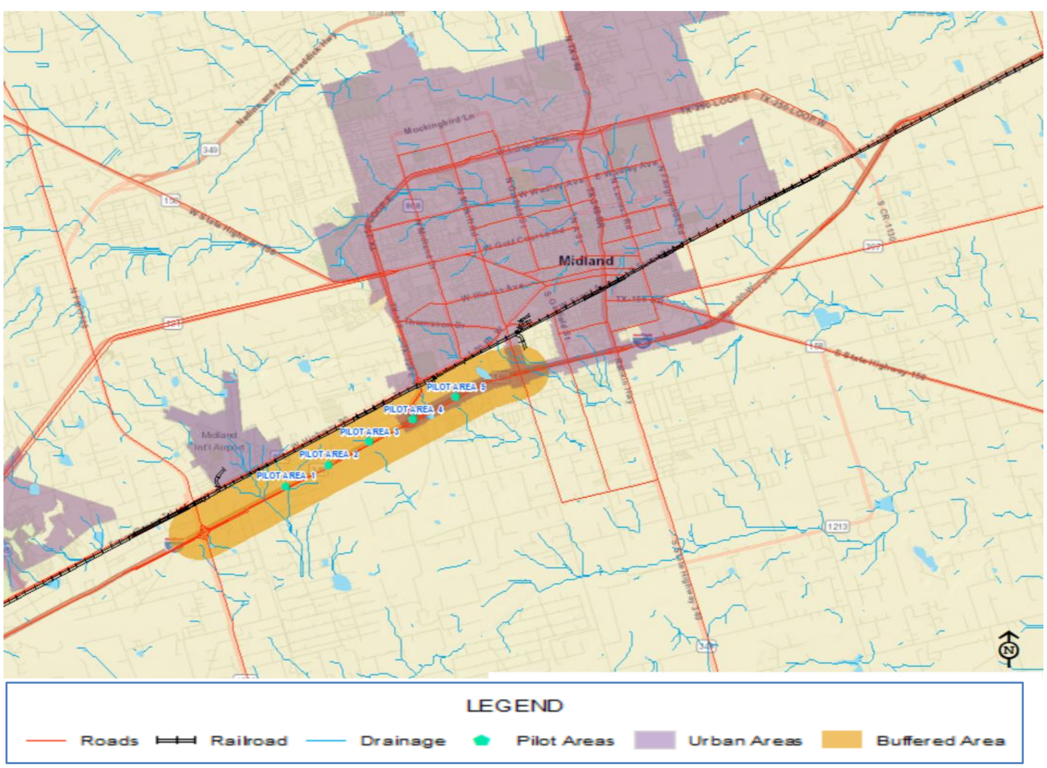
The study considered the diverse habitats and vegetation of the region and the materials that formed the soils of the area, the surface textures, and profile characteristics. If available, the study can use practically collected data to represent biological resources and socio-economic activities, adopting the NOAA criteria. And apart from protecting human life, this effort would reduce the environmental consequences of the spill and cleanup efforts. This objective is best achieved if sensitive resources are identified in advance so that responder can establish protection priorities and cleanup strategies selected. There is no time for responders to reach out to all the different resource managers and community leaders for information on what areas or resources are the most important and sensitive to protect in an accident.

To make the sensitive area mapping more effective, it must be a critical component of overall planning activity. TESI maps, in general, are essential decision-support tools and a crucial source of information to help responders with their decisions before, during, and after an incident. The final choice lies in the responder's responsibility to consider all relevant factors and provide the most effective spill response.

Annexes

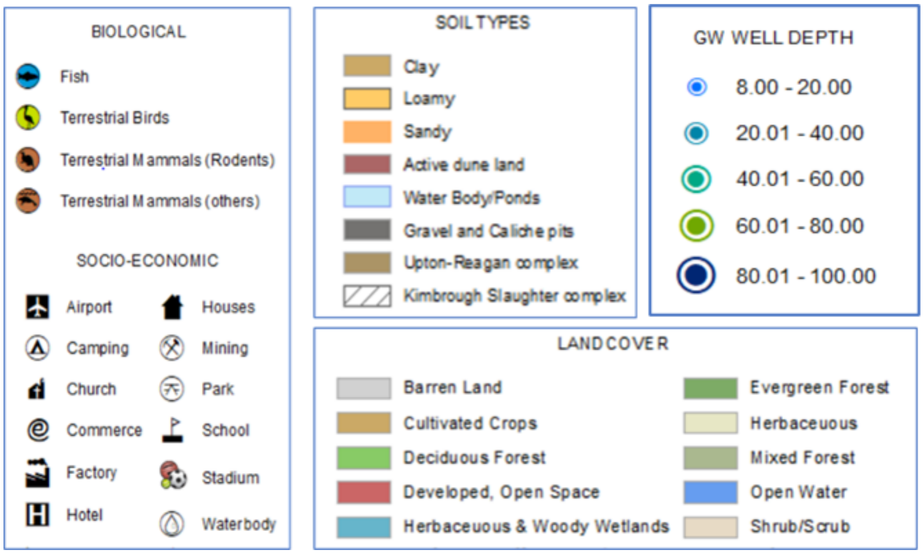
Annex 1

Map of the Midland City, Midland County in Respect to the Pilot Areas



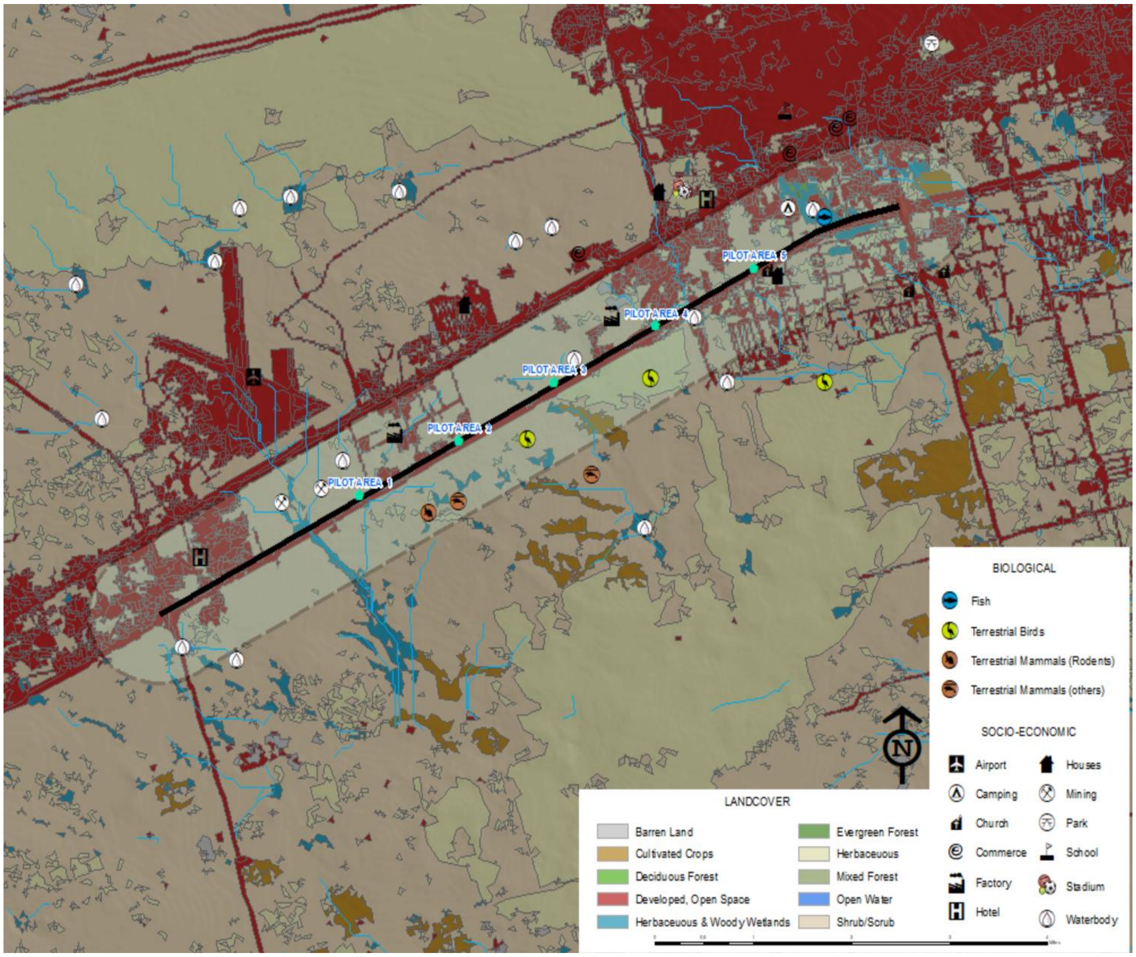
Annex 2

Symbols for Landcover, Soil Types, and Well Depths



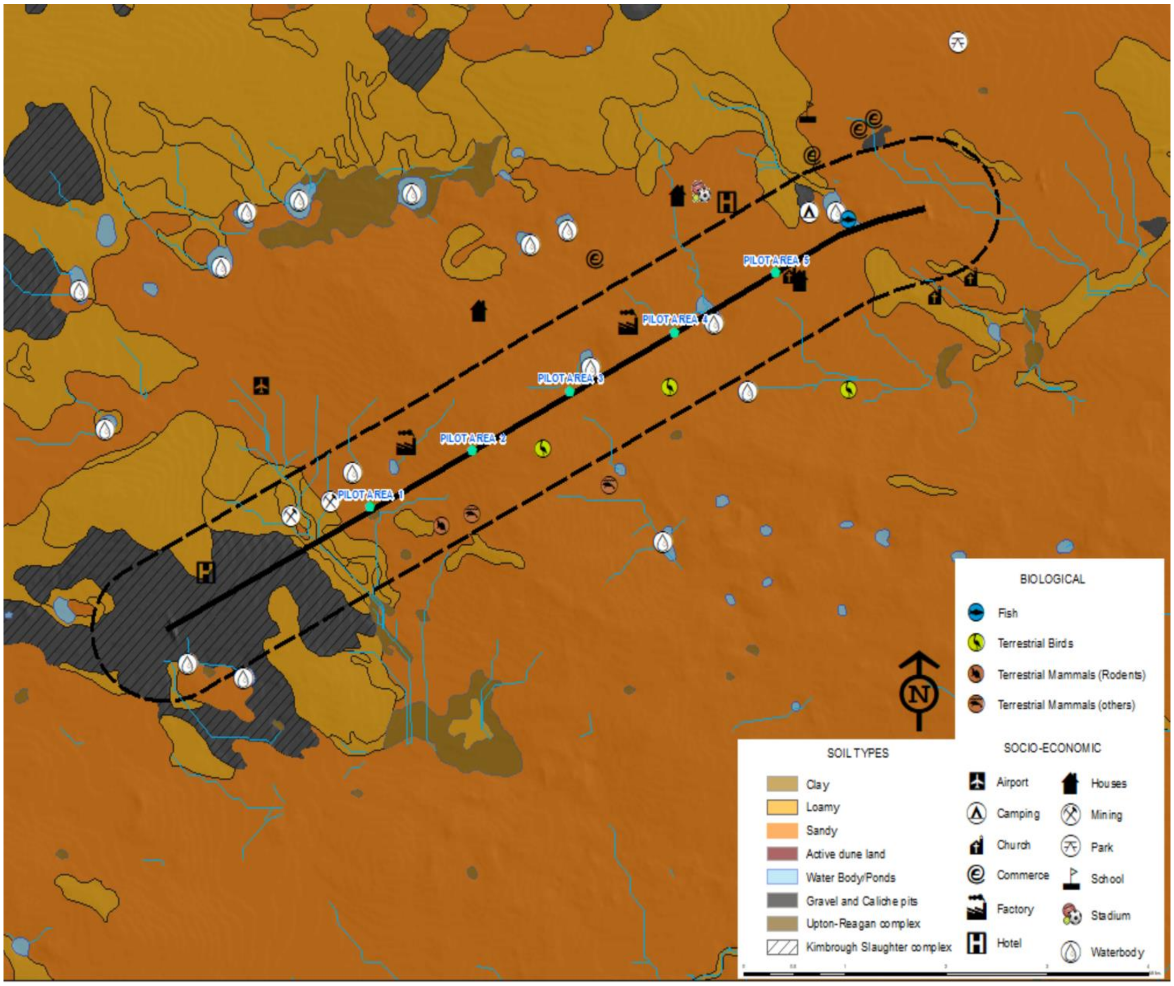
Annex 3

Spatial Distribution of Sensitive Elements in Respect to Land Cover



Annex 4

Spatial Distribution of Sensitive Elements in Respect to Soil Types



Annex 5

TESI Segments in the Pilot Area