Remote Sensing and GIS used in Oil Spill Remediation

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Oil spills can be a devastating anthropogenic disaster. While large tanker spills have greatly decreased over time, spills still occur from illegal discharges, machine malfunction, and pipeline disruption. Estimating annual total spill volume is difficult due to the range of sources but it is most likely in the hundreds of thousands to millions of gallons a year. Spills have lethal and sub-lethal effects on a broad range of organisms and ecosystems, including humans. Remediating spills is naturally difficult. Oil slicks disperse quickly, evaporate their most toxic components within 24 hours and are at the mercy of a wide range of environmental conditions. Being able to effectively track and predict spills can save an area from years of persistent pollution. There are three main steps in recovering from an oil spill that GIS and R/S can be helpful in, preparing, detecting and predicting. Preparing is done on a GIS platform, detecting is done by remote sensing, and predicting is a little bit of both.

In order to effectively respond to an oil spill responders need to be able to prioritize areas where oil would have the worst effects. Places that feature fragile organisms like mangroves or corals, or areas that are particularly sheltered and lack significant water movement should be prioritized. On the other hand, sandy beaches or quick moving tidal areas should allow the oil to naturally disperse. Having an ESI, or environmental sensitivity index, in place before a spill could potentially save years in recovery time. ESIs take into account three factors for every stretch of shoreline; shoreline sensitivity, biological resources, and human resources. Shoreline sensitivity looks at sediment type, water movement, and other abiotic factors. It is important in defining ease of clean-up and natural clean-up potential. Biological resources look at the productivity of an area and if there are any particularly fragile, important species present. Human resources look at how easily accessible the area is to response teams. ESIs require a ton of data, a luxury that not everyone has. GIS is a perfect match for an ESI because that data can be overlaid onto a map of the area. GIS allows for easy access and distribution of these plans and for potential manipulation if some factors change (Luwal and Oyegun 2017).

Detecting oil spills is inherently difficult. Being able to sense the oil is important for a number of reasons. There are an array of different remote sensing options but none represents a silver bullet. Radar is becoming the most popular remote sensing option for oil spills. Naturally water appears very bright in radar due to a high amount of backscattering from capillary waves. Capillary waves are small surface waves caused by wind. Oil slick will disrupt these waves and cause the surface to appear much darker in a radar scan. There are natural factors such as fresh water slicks or organic film that have the same effect on a radar scan producing false positives around 20% of the time. This method requires a range of wind speeds from 3 – 20 knots to create the necessary capillary waves. Overall radar’s ability to be used day or night and in foul weather over large scales makes it a very useful tool in oil spill sensing (Fingas and Brown 2014).

Remote sensing methods for oil spills represent a game of pros and cons. In the visible spectrum is cost-effective and reliable in high volume spills. It can also be used to differentiate slick volume at high
resolutions when combined with the near IR (Svejkovsky, Jan, et al. 2016). However, oil has no spectral qualities that definitively differentiate it from its background making positive detection using only spectral qualities impossible. Infrared can detect differences in heat emission caused by oil. During the day thick oil slicks appear hotter than surrounding water, while thin oil slicks appear cooler. A number of natural factors can cause false positives and IR sensors cannot detect very thin sheens or weathered emulsion. Laser fluorosensors represent a promising method of active remote sensing. Compounds in oil become electronically excited by UV radiation (one reason that oil is so devastating to photosynthetic organisms). This excitation fluoresces at different wavelengths than any naturally occurring compound. This is effective for generating in situ measurements of oil saturation. However, the compounds that this sensor is measuring may evaporate early on in the process, making it only effective in fresh, unweathered spills. These sensors are becoming a staple of oil spill remote sensing packages but work still needs to be done (Kim et al. 2010).

Determining spill thickness is an important factor in spill response. In order to most effectively and efficiently remove the most oil from a spill site, it is important to know where the thickest concentrations are. Radar while effective at locating slicks is useless in this regard as it only produces a positive or negative reading. High resolution (>10m) visible readings combined with IR have been shown to effectively differentiate different slick thicknesses. When done by using a satellite these readings can provide large-scale thickness maps. Unsurprisingly slick thickness is highest closest to the source and disperses significantly over time and space. When the oil has dispersed it has been shown to accumulate into four different thicknesses that require different sensing methods to differentiate. Nanomolecular sheens are only apparent using radar, thin and thick slicks are differentiated by IR thermal readings, and emulsion is most detectable in visible readings (Svejkovsky, Jan, et al. 2016).

Predicting where spills will travel is a daunting task. Guo commented that the “processes affecting spills are complex, even chaotic”. Oil spills have been recorded traveling hundreds of kilometers in a single day and experience random diffusion. There are four main variables that are important when trying to predict where a spill will travel; location, magnitude, time, and chemical composition. Magnitude looks at the sheer volume of oil spilled, the location at the specific spot where the spill occurred and the many processes occurring there, time at the seasonal and tide conditions, and chemical composition determine how that fuel will diffuse. The prediction model most commonly used is the OSRA (Oil Spill Risk Assessment) which attempts to determine probabilities that a spill will reach certain sites and the probable arrival time. The model treats oil as a collection of particles that are influenced by advective factors, such as wind and current, as well as random diffusion. Interestingly the model dealt only with probabilities and was run in 500 different simulations in GIS in order to obtain these estimates. The results of this model reliably matched the results of a real spill (Guo et al. 2016).

An example of these technologies coming together to form an effective system is found in the PRIMI system in Italy. The Mediterranean represents a very busy waterway with tons of shipping traffic. Illegal discharges are very common and PAH (a toxic oil component) measurements are unusually high there. In response, the Italian government put together an oil spill system that combines detection, prediction, and response. An aircraft equipped with SAR and wider view optical sensors performs surveillance. The images captured are run through a software that determines the likelihood of each
result being a spill. These spills are then run through a GIS program MEDSLIK II which estimates a prediction of the trajectory of the spill. This represents a model system that should be copied throughout countries with oil spill problems.

In my opinion, the future of oil spill detection lies in more advanced sensors and drones. Higher resolution images and more frequent satellite passes have already proven to dramatically improve oil spill coverage. As these technologies continue to advance the coverage will only improve. Laser flourosensors represent a technology that could both detect spills and determine concentration but need to be scaled up. An interesting area of research I couldn’t find much about is how drones are being used. I could imagine a long-range drone equipped with even a relatively low-resolution radar could automatically track an oil slick 24/7. Providing around the clock coverage would provide responders with up to the minute data. Drones could also be capable of cost-effective surveillance in ports with frequent illegal discharges. Prediction software will also most likely improve with computer technology, however, it is already fairly accurate and reliable. Being able to use this prediction technology in the field and inputting real-time environmental conditions would even further improve their accuracy.

GIS and remote sensing are crucial in all stages of oil spill response. These technologies have been constantly improving and will only continue to improve over time. From preparation to detection to prediction, these spatial technologies are indispensable.

This paper documents the creation of an environmental sensitivity index in the Rivers State region of Nigeria. ESIs are an important tool used in oil spill remediation. It takes into account three factors: shoreline sensitivity, biological resources and human resources. Shoreline sensitivity is defining the ease of anthropogenic clean up as well as potential for natural clean up. This paper emphasized the significant gap in data in environmental monitoring between wealthy to poor countries. In order to create the ESI, they operated three stages, identification and collation of required data, definition of the knowledge-based rules, and GIS-based modeling of the rules. In order to categorize the environmental sensitivity of a shoreline, data on shore types, slope, wave exposure, and sediment types were collated. The definition of the knowledge-based rules was adapted and modified from the Oil Producers Trade Section and NOAA guidelines for creating ESIs. Each shoreline unit was assigned a shoreline sensitivity index (SSI) based on the shoreline type and its shelter from waves, with highest values indicating highest sensitivity. Finally, the data was stored and manipulated within ArcGIS where the knowledge-based rules were implemented by a conditional algorithm in association with GIS stored data. Using this they determined that 78% of their shoreline is highly sensitive to oiling with a rank of 7-10, with much being sheltered mangrove forests where natural conditions would allow the oil to sit.


This paper describes the testing of the PRIMI modular oil spill detection and forecasting system, the first system to integrate observation, detection, and forecasting of oil spills. The system is made up of a SAR and optical module for detection, a forecast module for oil spill displacement forecast and an archive module that provides data storage and web-GIS services for users. Synthetic Aperture RADAR (SAR) is a satellite-based sensor with a high spatial resolution that detects the dampening effect of oil film on capillary waves generated by wind, resulting in dark areas that indicate pollution. SAR has its limitation such as it needs wind to be effective and that it provides limited spatial coverage, so it is backed up by optical sensors which provide wide coverage and are more effective with limited wind. The SAR module also consists of Oil Spill Detector software, which scores every image with a percent chance it is a real slick. Forecasting provides data in near real-time with can be used to assess potential environmental risks and aid in the decision making in the remedial process which is necessary because slicks can move tens of KM over the spans of hours. The Italian national research vessel the Urania searched 13 spill sites, 12 identified by SAR and 1 by optical detection, to obtain in situ results. The SAR system correctly identified spills 8 of 13 times with optical detection confirming 4 of those spills.
This paper is a review of the pros and cons of a number of different remote sensing tools for sensing oil spills. The main purposes of using remote sensing during an oil spill are mapping spills, surveillance and detection of spill, evidence for prosecution, enforcement of ship discharge laws, direction of countermeasures and determination of slick trajectory. In the visible spectrum oil has no characteristic that differentiates it from its background, making positive identification using only visible tools impossible. Oil absorbs and reflects heat differently than water so the infrared can be effective in identifying slicks, however many natural factors can produce false positives. Laser flourosensors use UV radiation to excite oil into fluorescing in a unique way with different oil types fluorescing differently. Radar can be used to survey large areas by detecting a lack of surface clutter in oiled areas with a relatively high rate of natural false positives. Detecting spill slickness requires accuracy on a very small scale and is still a developing technology. This paper highlights advances in satellite availability as an important recent development and the potential of laser flourosensors and passive microwave techniques.

This study used a variety of remote sensing methods to determine characteristics of oil slick thickness on the surface. Due to the Deepwater Horizon spill’s continuous nature and wide area of effect, the spill became the most remotely sensed oil spill of all time. The most frequently collected data was SAR and SLAR collected from planes while daily high-resolution multispectral and infrared images and multiple levels of satellite data were also collected. SAR satellites were found to be very useful due to their frequent coverage and independence from weather conditions, but were incapable of determining thickness. The thickness characteristics were based on high resolution (2m) digital microspectral images which yielded 3 visible bands at 12-bit resolution and an algorithm. The high-resolution satellite Wavelength-2 provided one day of large-scale, high resolution (2m) data that was able to be analyzed using a similar algorithm due to its similarity to the multispectral images. Much lower resolution (30m) satellites imaged the spill area but had difficulty providing meaningful data because some high volume strands of oil only run a few meters across. The study found that oil collected predictably away from the well into four separate categories, sheen (invisible to everything but SAR), thin (.04-5 μm) and thick slicks (6-70 μm) and emulsion (significantly weathered oil that appears in long strands).

This study focuses on using a real oil spill event and real observed environmental conditions to verify the reliability of their model. The important environmental assessment tool OSRA (oil spill risk analysis) model attempts to assign probabilities that a spill will affect an area as well as determine the spills arrival time. Due to the many different factors that influence oil spills, attempting to model them can be extremely difficult. In order to obtain realistic results, a model must mainly contend with four different
variables; location, chemical composition, time, and magnitude. This model regards oil as a collection of particles that are subject to a number of advective forces as well as random diffusion. In order to create an influence map of the spill zone depicting where the oil will likely go and when it will likely get there, data is run through a seven-step flowchart. The numerical model was able to model the size of the slick to within 4 km. In order to judge the effectiveness of their model, they ran 500 simulations each in 2 trials, one trial taking place with random seasonal conditions and the other with environmental conditions seen during the real spill. They found in both spill arrival probability and predicted arrival time the model with the real environmental conditions were reliably close to the real results.


Measuring the amount of oil dissolved in water with the conventional gas chromatography method is effective but time-consuming and costly. Recently laser fluorescence has proven to be able to reliably and accurately determine oil concentration in situ. Laser fluorescence relies on the fact that when excited by UV radiation certain compounds in oil will fluoresce at unique wavelengths. This study compared readings from gas chromatography to laser fluorescence in monitoring oil saturation in seawater. They found that fluorometric were unreliable with significant amounts of weathered oil or in low oil concentrations. At high concentrations the relationship between the two measurements was significant. The study hypothesized that compounds that fluoresced in the oil evaporated out relatively early in the weathering process. However laser fluorescence shows potential as a quick and cheap in situ measurement for oil concentration at a larger scale.