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University of Redlands

A Spatial Analysis of African Oil and Gas Infrastructure Security

A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

by

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Douglas Flewelling, Ph.D., Committee Chair
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August 2014

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The report of Jesse Hamlin is approved.

Mark Kumler, Ph.D.

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Abstract

A Spatial Analysis of African Oil and Gas Infrastructure Security

by

Jesse Hamlin

Many countries and governments around the world rely on the production of oil and gas resources. The high cost of the assets and infrastructure used to produce these resources makes them a prime target for terrorist attack and theft. As a result, the security of oil and gas infrastructure is becoming exceedingly important. Both governments and private companies are interested in protecting the infrastructure used to extract, transport, and refine these resources in many places, including Africa. Geographic information systems (GIS) has the ability to assist with mapping infrastructure and assets, performing spatial analysis concerning areas of high-risk or vulnerability, and creating web-mapping systems that allow users to view and upload information as they acquire it. The end goal is to contribute to the protection of the oil and gas industry, and government's dependent on this industry, from imminent and future threats.

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List of Acronyms and Definitions

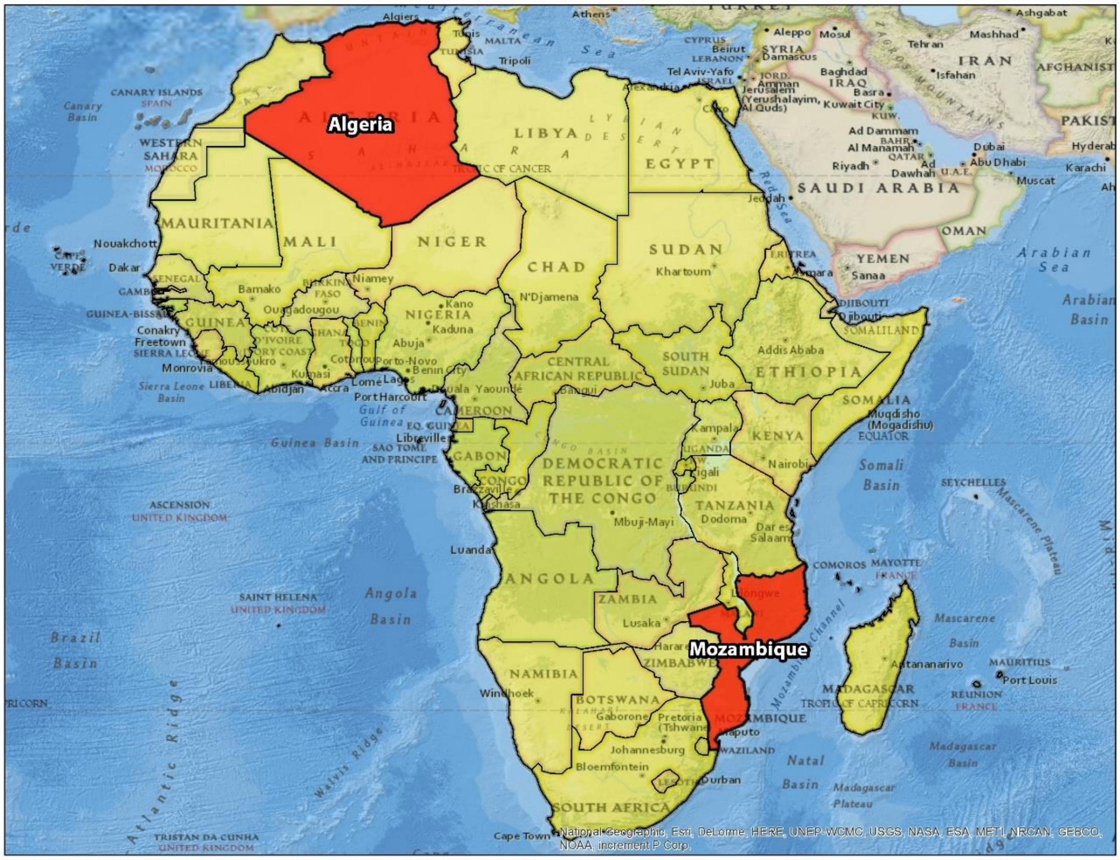
ACLED	Armed Conflict and Location Event Data Project
AGOL	ArcGIS Online
CSV	Comma Separated Values
EP	Exploration and production
GDB	Geodatabase (Esri)
GIS	Geographic information systems
GTD	Global Terrorism Database
IIS	Internet Information Services
ITS	Information Technology Services
LIDAR	LIght Detection And Ranging
LNG	Liquified natural gas
OG	Oil and gas
NGA	National Geospatial-Intelligence Agency
NIMA	National Imagery and Mapping Agency
RSS	Rich Site Summary (aka Really Simple Syndication)
SCAD	Social Conflict in Africa Database
SNC	Sierra Nevada Corporation
SOCOM	United States Special Operations Command
UR	University of Redlands
WAB	ArcGIS Web App Builder
WGS84	World Geodetic System 1984

Chapter 1 – Introduction

This project focused on the security aspect of oil and gas (OG) infrastructure in Africa. There have been many events in recent history where terrorist attacks or oil theft has taken place. In order to prevent these attacks in the future, a GIS solution was implemented. Several tasks were performed, including acquiring an initial spatial database of OG layers for the client, performing spatial analysis in order to determine high-risk areas vulnerable to attack, and constructing an online web-map. Tools in the web map enabled the client to use standard web mapping tools such as changing basemaps, measuring distances and areas, and drawing tools, as well as being able to upload their own spatial data. By being able to view, analyze, and update information through GIS, future attacks can be better predicted, examined, and responded to in greater detail.

1.1 Client

The client for this project was the Sierra Nevada Corporation (SNC). The point of contact at SNC was Jim Wickman, Director of Fusion and Transformation. SNC has been sub-contracted by the United States Special Operations Command (SOCOM) to gather intelligence in Africa. Of particular interest to SOCOM is the mapping of existing oil and gas assets that might be vulnerable to attack; such as pipelines and refineries, as well as determining how to monitor those assets. The client was interested in a web mapping system that could be implemented to allow data to be added and integrated. The client identified two specific countries of interest in Africa: Algeria and Mozambique (Figure 1-1).



National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Figure 1-1: Study area priorities as identified by the client.

1.2 Problem Statement

Oil & gas infrastructure security is becoming an increasingly important issue, especially on the continent of Africa. This problem can be attributed to a number of factors that revolve around terrorism and theft. In Algeria on January 16, 2013, the In Amenas hostage crisis took place in which a group of militia believed to be associated with Al Qaeda took more than 800 people hostage at the Tigantourine natural gas facility. At least 39 foreign hostages were killed including three Americans (British Broadcasting Corporation, 2013). This is just one example of what governments in developed countries (such as the United States and those in Europe) are trying to prevent. Another is the theft and sabotage of crude oil in Nigeria by rebel groups. In this case, pipelines are illegally drilled into and oil is collected and sold on the black market to other countries and governments. Some estimates put the potential oil revenues lost to theft over the past two years in Nigeria at close to $11 billion dollars (Reuters, Nigeria Loses $10.9B to Oil Theft, 2013). Offshore oil rigs are at risk for pirate attack and ransom, with several reported cases taking place in Nigeria. GIS is a tool that has the ability to assist. The first step is by mapping out the existing infrastructure. It is difficult to prevent these types of events without knowing where the infrastructure is located. GIS and spatial analysis can assist by helping to predict where these attacks will occur in the future. This helps contribute to a reduction in future attacks, as well as an improvement in response time once an attack or theft does take place.

1.3 Proposed Solution

1.3.1 Goals and Objectives

There were three primary objectives for this project. The first was to perform limited data acquisition (50 hrs. of OG data) and create a standardized, normalized spatial geodatabase for the client. This database was the primary deliverable for the client.

The second objective of the project was to use GIS to identify areas of high security risk to OG assets on the African continent, based on several factors relevant to security. An integrated risk index method was designed to follow an approach taken by Cova (1999). This approach used several variables to produce individual hazard and vulnerability maps, from which a final risk map was derived. This objective assisted the client in fulfilling their need of effectively protecting and securing existing assets.

The third objective was to create a web mapping system that allows the client to view data and retrieve information, and to use basic GIS tools in a web-mapping interface. The application needed to be accessible from mobile devices and desktop computers, and needed to allow the client to import future data.

1.3.2 Scope

The project was completed over a ten month period. Frequent meetings via Skype took place with the client. Deliverables included a geodatabase, a set of risk layers, and a web map with data upload capabilities. The client provided updates and communication with the contractor, as well as ensuring data was acquired from the data provider. The audience for this project consisted of several possible stakeholders and user groups, including Sierra Nevada Corporation (SNC) and the United States Special Operations Command (SOCOM) intelligence analysts and project managers, as well as subsidiary organizations such as US Africa Command and the US State Department. In addition, the application might be used by potential commercial subscribers in the OG, insurance, and supply chain logistics management industries (through SNC's internally funded research and development concept of Analysis as a Service or AaaS).

1.3.3 Methods

Several steps were taken in the technical solution to this project. The first was the compiling of spatial data into a standardized Esri file geodatabase. The second component of the project was performing spatial analysis. Using an integrated risk model from Cova (1999) as a baseline, 20 variables relevant to OG infrastructure security (based on an independent literature review by the contractor) were assembled and assigned weights in Esri ArcGIS. This was used to produce three primary output maps: hazard, vulnerability, and overall risk. Finally, the creation of the web map was produced using the ArcGIS WebApp Builder and ArcGIS Online.

1.4 Audience

This report was written for audiences involved in the OG industry. As such, the GIS terminology in this report is generalized into non-technical language. The client (Sierra Nevada Corporation) will be the primary audience. Components of the project also have the potential to be used in a service-based subscription to other companies in different industries (as per client). These include insurance, supply-chain logistics management, and OG industries.

1.5 Overview of the Rest of this Report

Chapter 2 focuses on previous work done in spatial risk assessment, pipeline security, and oil and gas infrastructure characteristics, through a clearly defined literature search review. Chapter 3 revolves around the actual solution design that was used to solve the client’s problem. Chapter 4 consists of a full section on database design. As a core element of GIS, data and data compilation are key to producing GIS deliverables. Chapter 5 examines the implementation phase of the project. In Chapter 6, the analysis and results of the project are described in detail. Chapter 7 describes the conclusions, as well as future work that could be conducted as an extension to this project.

Chapter 2 – Background and Literature Review

There are two major reasons why oil and gas security (OG) is a major issue for governments and private companies. The first is the lucrative financial benefits the industry generates; the second is the damaging effect the destruction of OG assets can have on the owner by opposition (e.g., disgruntled employees or terrorist groups). Large amounts of money are required to create the infrastructure used to support the OG industry. OG systems are by nature very connected systems. If one component of the system is damaged, it affects many other parts of the system. GIS has an increasingly effective role in being able to assist with these types of issues. Johnston (2004) argued that “GIScience and tools are becoming especially effective at (1) reducing threats, (2) detecting threats, (3) reducing vulnerabilities to threats, and (4) improving responses to terrorism” (p. 997). The following sections will discuss three topics. First, how GIS is used to assess risk. Second, how GIS can be used to reduce and detect threats for pipeline infrastructure, one of the primary targets for attack. The last section will consist of a review of basic OG infrastructure security protective measures.

2.1 Assessing Risk Using GIS

Risk is often defined in geography as pertaining to some degree or level of uncertainty of a negative outcome occurring. The goal of risk assessment is to assign a value or score to a particular event. Cova (1999) states that GIS is gaining in favor in comparison with traditional methods of risk assessment. Several studies have used GIS to assess and model risk from a spatial perspective relevant to this project (Cova, 1999; Cutter, 2000; Greiving, 2006; Collins, 2009). One thing all of these studies had in common was the method with which they tackled risk assessment. Variables that contribute to risk were identified and then subsequently grouped into one of two categories: *hazard* and *vulnerability*. According to Alexander (1993), “hazard is a pre-disaster situation where some risk of disaster exists, principally because the human population has made itself vulnerable in some way” (p. 848). Examples of hazard in Cova’s (1999) model include technological hazard variables from the built environment such as the presence of toxic sites, nuclear facilities, and hazardous material routes, as well as natural hazard variables such as geological faults, vegetation, and topography.

The second category is *vulnerability*, which are often associated with the human environment. These include characteristics such as population density, proximity to major roads, and social unrest or conflict in a region. In Alexander’s model, risk was viewed as a combination of hazard and vulnerability. He presented a basic definition relating hazard and vulnerability originally taken from the Office of the United Nations Disaster Relief Coordinator (UNDRO) (United Nations Disaster Relief Office, 1979) where risk is viewed as a combination of hazard and vulnerability (Equation 2.1).

$$Risk = elements\ at\ risk * (hazard * vulnerability) \qquad \textbf{Equation 2.1}$$

All literature cited thus far maintain the same basic principle: risk is derived from some combination of hazard and vulnerability. A more detailed version of the equation breaks down each individual variable where:

$$Risk = R(H(E_h),V(E_v))$$ **Equation 2.2**

H is a function of the elements of E_h; vulnerability is a function *V* of the vulnerability of elements E_v ; and risk is a function *R* of the results of the hazard and vulnerability functions (Cova, 1999). All hazard variables are tied to hazard and all vulnerability variables are tied to vulnerability in the calculation of an ultimate risk score for each. By determining these scores and assigning them to locations, a risk mapping solution can then be implemented. This involves using the hazard variables to produce both a hazard model and a hazard map. Vulnerability variables are then used to produce a vulnerability model and vulnerability map. When these two maps are combined, a risk model and final risk map can then be generated.

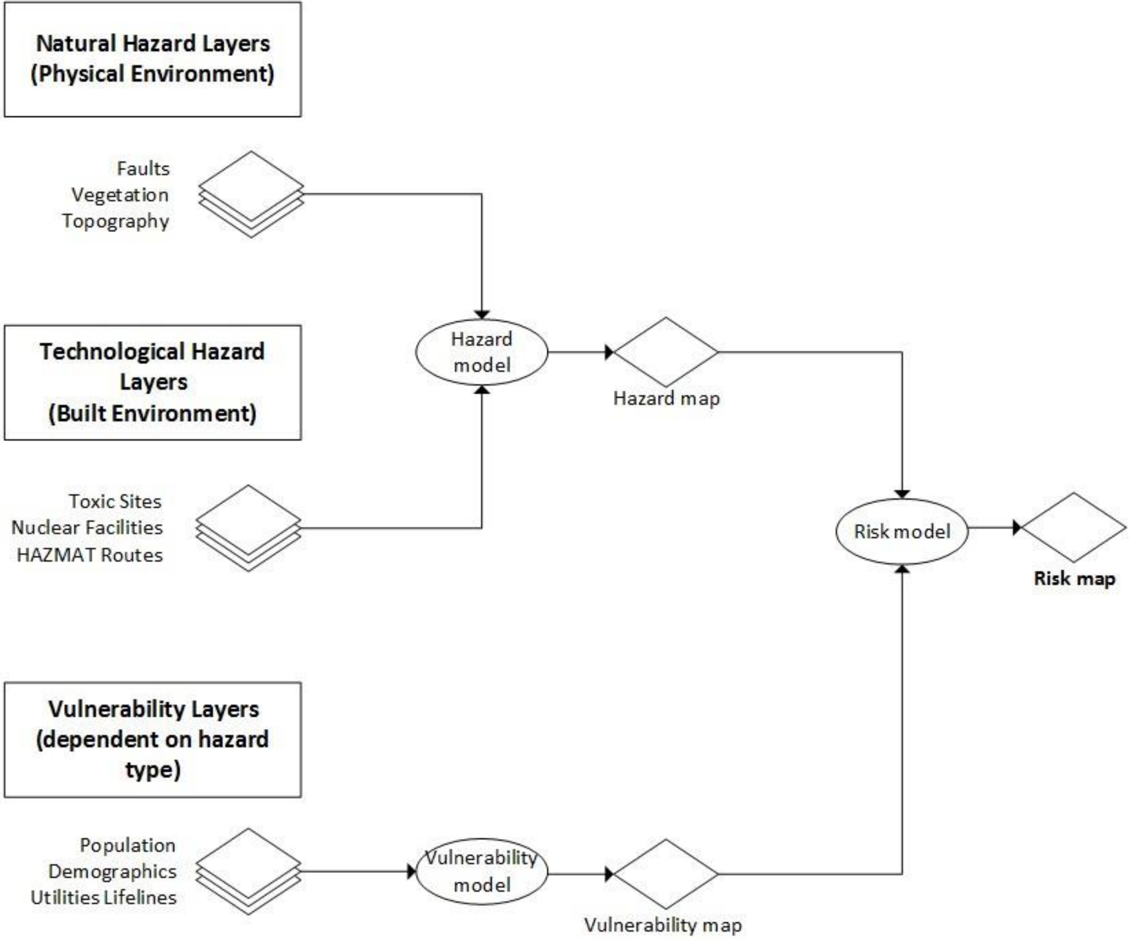


Figure 2-1: An approach to modelling hazard, vulnerability, and risk. Adapted from Cova (1999).

The 2006 Greiving study provided a more detailed framework for assessing risk by assigning particular weights to each of the variables based on a Delphi method (survey information provided to Greiving from industry professionals). The approach is known as an integrated risk assessment of multi-hazards. Hazard and vulnerability maps were produced, this time taking it one step further by describing ordinal classes of intensity in the range of 1-5. Lastly, an integrated risk map using a combination of hazard and vulnerability potential was adapted from Greiving (2006) using the following matrix (Table 1).

Table 1. Integrated risk value matrix

Hazard Intensity↓	**Degree of vulnerability→**	**1**	**2**	**3**	**4**	**5**
1		2	3	4	5	6
2		3	4	5	6	7
3		4	5	6	7	8
4		5	6	7	8	9
5		6	7	8	9	10

One problem with this approach was that many of the values are clustered near the center (i.e. in the 4, 5, 6, and 7). This is due to the addition method used to calculate the risk value. In this method hazard and vulnerability are added together to produce risk values (Equation 2.3).

$$Risk = Hazard + Vulnerability \qquad \textbf{Equation 2.3}$$

The problem with this methodology is that the output values closely follow the normal distribution. This has a clustering effect of values near the center of the risk scale. If risk and vulnerability are instead multiplied together, the resulting values are more dispersed. This allows for more efficient visualization and interpretation (Figure 2-2).

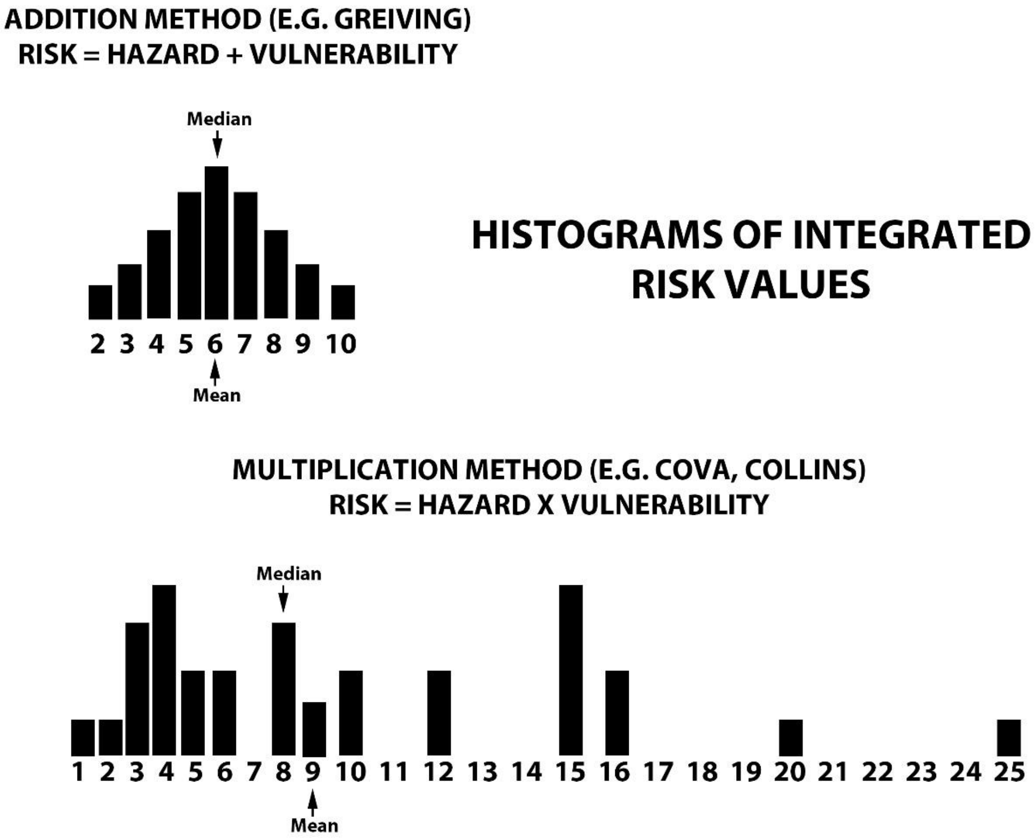


Figure 2-2: Histograms of integrated risk value

Collins (2009) describes a similar spatial risk methodology. In this method, flood risk in the El Paso-Ciudad Juarez metropolis (USA/Mexico) was explored. Risk was presented as a combination of hazard and vulnerability, but the difference was that the reason for this policy was more clearly explained. In essence, there was a dependency between the two variables hazard and vulnerability. The presence of one without the other will yield negligible or zero risk.

> "A critical point is that even a high magnitude hazard event poses no risk when it occurs in the absence of vulnerable population. Conversely, a vulnerable population – such as one that lacks access to protective resources – experiences no risk if there is not a probability of a hazard event occurring in their presence" (Collins, 2009, p. 449).

This is why the two factors hazard and vulnerability are multiplied together to produce a risk score. If one value is given a zero value, the final risk score returned will be zero. The methodologies described in Section 2.1 were the basis for the GIS-based risk model used in this report.

2.2 Pipeline Security Assessment

One of the main types of infrastructure that can be targeted for oil theft and terrorist activities is pipeline infrastructure. The high cost and damaging consequences of an attack on a pipeline make these prime targets for militant groups. Thus, the security of pipelines is one of the primary facets of OG security that needs to be considered. Pipelines often span long distances, which makes them problematic and expensive to monitor.

Roper and Dutta (2005) presented several GIS and remote sensing applications for pipeline security assessment. With the advance of modern computing technology and storage devices, the ability to capture new forms of data at a more rapid pace was feasible. Examples of new technologies/methods given in the study included satellite based monitoring, light detection and ranging (LIDAR), terrain analysis, monitoring using airborne vehicles, and thermal infrared imaging. In particular, LIDAR and thermal infrared remote sensing were of interest. It was discovered that LIDAR "provides rapid 3-D data collection of long, linear objects such as pipeline corridors" (Tao, 2002, p. 2). This means that highly inaccessible areas can be flown via air transport and LIDAR points recorded for use and visualization within a GIS. Roper (2005) cites another case study: "In one study satellite imagery and target identification analysis is used to detect unauthorized intrusion onto a pipeline right-of-way in a remote area of Canada" (Roper & Dutta, November 2005, p. 2). LIDAR is particularly effective at capturing linear features because its sensors have a narrower swath width than other optical sensors. Not only are pipelines able to be detected, but unauthorized intrusions are also able to be distinguished. Innovative applications such as this can be applied to many different parts of the world, including the intended study areas in Mozambique and Algeria.

Roper and Dutta go further to identify thermal imaging as useful for pipeline detection primarily because it offers the ability to distinguish pipelines at night, due to temperature differences between pipelines and the ground. This separates it from other optical sensors, which typically are only able to reveal useful information during the day with proper daylight, and with good weather (i.e., low cloud cover). Another application for thermal imaging discusses differences between buried versus above ground pipelines. This is important because underground infrastructure is much more difficult for militant groups and thieves to attack.

Another application for GIS in pipeline security is in visualization and mapping. Visualizing and managing pipelines in GIS mapping systems can be very valuable in comparison with viewing information in tabular format. "The ability to visualize pipeline features has proven to be a powerful tool for decision-makers – saving valuable time and resources" (Clemonds & Isaacs, 2010, p. 1). Managing from a geographic viewpoint allows users a better way to assess assets and recognize possible dangers or hazards. One of the core functionalities of GIS is mapping, and thus the difficulty of implementing this type of solution in asset management is inherently low.

2.3 Infrastructure Characteristics and Protective Measures

In order to understand how GIS can most effectively assist with the problem of infrastructure security, one must get a sense of infrastructure characteristics and the attractiveness of individual targets for terrorist attack or theft. OG infrastructure is often an easy target for terrorists and thieves because by nature it is spatially concentrated. This is especially true for assets such as refineries, oil wells, LNG terminals, and offshore oil platforms. The attacks by the retreating Iraqi government on Kuwaiti oil fields in the 1991 Persian Gulf War, in which 700 oil wells were set ablaze (Hirschmann, 2005), is just one example. In terms of specific assets, Farrell (2004) suggests that three types of infrastructure are prime targets. The first is liquified natural gas (LNG) facilities. The high cost and time required to construct these facilities makes them attractive for militant groups to attack (Farrell, 2004). The explosive properties of natural gas also make LNG infrastructure (pipelines, terminals, facilities) a more attractive target than some oil-based infrastructure. The other two major asset classes vulnerable to attack are refineries and pipeline pumping stations. This is because these assets are usually of limited supply, and typically service large areas. An attack on a refinery or pipeline pumping station can affect entire networks of an OG system. Without a refinery to refine petroleum products or a pipeline to transport them to the facility, delays can arise. The destructive potential of these three asset classes must be considered when assessing areas vulnerable to security risk using GIS.

Critical Infrastructure Protection (CIP) is a term that is used throughout the industry to describe preparation and response to incidents involving attacks on infrastructure. One of the primary focuses of CIP is to prevent any supply and/or pricing interruptions from taking place. “A sudden loss of production capacity because of terrorist attacks, or any other major damage to energy infrastructure, would bring about immediate shortages of supply, which in turn would cause prices to spike” (Rudner, 2009, p. 777). Blackouts and oil embargos are also a consequence of infrastructure attacks (Farrell, 2004). A set of protective measures must be established in order to protect infrastructure from attack. Farrell describes several key recommendations for preventing or at least diminishing the destructive nature of a terrorist attack. The first is energy diversity. By having different types of energy (oil, natural gas, coal, wind, solar), a country’s infrastructure is much less vulnerable. The second key method for achieving reliable energy supply is storage and redundancy. If an organization has only a handful of facilities, they may be more at risk of catastrophic failure should an attack or theft take place. The next protective measure is that of exclusion zones. These are physical or administrative barriers or buffers (often called setbacks in the OG industry) located around key OG infrastructure. Examples of this can be found in the offshore OG industry. Secure (e.g. 500 meter) and cautionary (e.g. 15 nautical mile) zones around offshore OG platforms have been recommended in both Asian (Cordner, 2011) and Australian (Kashubsky & Morrisson, 2013) studies. In terms of onshore boundaries, militarized protection zones are currently being utilized by many countries in the world, including those in North Africa. For example, “Algeria is currently using militarized protection zones for its hydrocarbon assets, which are patrolled by aerial and ground forces and can only be entered with special permits” (Smith Stegen, 2012, p. 12).

The last measure that needed to be understood was cyber-security. In this measure, OG facilities are at potential risk of blackout or damage from computer-based viruses that affect the facility’s computer networks. This measure is spatial because many computer viruses still need to be transmitted through on-site facilities. This approach is particularly noteworthy, because these types of attacks can be accomplished with limited financial or technical resources. Considering the advancement of access to technology over the last decade, this method is likely to become more prominent in the future.

2.4 Summary

By looking at how GIS was currently used to assess risk, an integrated risk model was generated in order to assess risk from an OG infrastructure security context. Before looking at the types of infrastructure that are at risk, it was imperative to examine several ways in which infrastructure was currently defended. This included several methods such as diversity, storage and redundancy, exclusion zones, and the threat of cyber security. In order to protect assets and respond to threats efficiently, it was important to understand which types of infrastructure were at higher risk. Based on the research conducted, these types of infrastructure included large scale, high-cost assets such as LNG terminals, refineries, and pipelines. These were the types of GIS information that were useful for security experts to visualize, and would allow them to be able to predict where future attacks would occur. The next section will describe the project requirements and system design that were acquired and integrated into a solution for the client.

Chapter 3 – Systems Analysis and Design

The following chapter will discuss the overall system design for the project. Section 3.1 discusses the problem statement for the client. Section 3.2 discusses the requirements of the client. Section 3.3 goes into detail on the actual design components, and Section 3.4 discusses the project plan that was devised for the project.

3.1 Problem Statement

Many people have lost their lives over the last few decades due to OG infrastructure attacks. Several OG companies such as Norway's Statoil and the United Kingdom's British Petroleum Group have simply decided to cease business in countries such as Algeria where attacks are common (Reuters, 2014). This can potentially lead to both domestic and foreign job losses, as well as a loss in economic benefits for the host country. Terrorist attacks and theft on OG infrastructure are becoming increasingly important issues on the continent of Africa. The client (Sierra Nevada Corporation) and subcontractor (SOCOM) are interested in protecting existing infrastructure, predicting where incidents will occur in the future, and decreasing response times once an incident does take place.

3.2 Requirements Analysis

Client requirements were separated into two separate industry standard classes: functional and non-functional requirements. Functional requirements describe behavior requirements of the solution, whereas non-functional requirements pertain to any performance-related, technological, or software requirements that were required to produce the deliverables.

The first functional requirement for the client was to acquire several oil and gas datasets from different vendors. The second requirement was to deliver a standardized, normalized geodatabase consisting of relevant oil and gas layers such as pipelines, oil refineries, natural gas facilities, and oil and gas wells. The next requirement was to deliver several risk layers pertaining to oil and gas infrastructure security risk. These were derived from a standard risk formula methodology adapted from Cova (1999). The client also required a visualization tool to be able to view all the previous information in a standard web-mapping interface. As part of the web map, the client also required standard web mapping tools such as the ability to pan, zoom, and select individual layers for additional information. The ability to turn on different basemaps, create bookmarks, and perform standard measurements and select locations was also created for the client. Table 2 lists the functional requirements necessary to produce the deliverables for the client.

Table 2. Project functional requirements

Functional Requirements	**Description**
Data acquisition	The system included a detailed OG infrastructure dataset (pipelines, wells, facilities) acquired from a reputable vendor
Geodatabase	The system will produced a standardized, normalized OG database
Risk Formula	The system's risk layer outputs will be based on a standard spatial risk formula: Risk = R(H(Eh), V(Ev))
Risk area layers	Low and high detail risk layers will be produced displaying areas of high and low security risk
Visualization	System shall allow user(s) to view OG mapping data in an online web mapping interface
User experience	System shall allow user(s) to pan, zoom, and select individual layers and pull up attribute information

There were six primary non-functional requirements for the project. The first was the use of the ArcGIS Spatial Analyst extension. This software was necessary to create the risk layers for the project. ArcGIS Online (AGOL) and the ArcGIS Web AppBuilder Beta 1 (WAB) were also required to produce the web application for the client. AGOL was used to create and store the data and web map, as well as provide login credentials. WAB was used to create the application itself, and create and customize the individual widgets, as well as style the application to meet the clients needs. The next non-functional requirement was the use of ArcGIS 10.2 software. This was used to run basic geo-processing tools such as buffers, clips, merges, dissolves, and others, which were required for data pre-processing for both the geodatabase and the risk layers. The next requirement was to produce help documentation for the client on how to upgrade to the full version of WAB and AGOL once the trial organizational account expires and the contractor leaves the project. The last requirement was for the application to allow the client to upload its own shapefiles. Detailed information can be found below (Table 3).

Table 3. Project non-functional requirements

Non-Functional Requirements	**Description**
ArcGIS Spatial Analyst	The risk map outputs were created by converting from Vector to Raster and using Raster Calculator
ArcGIS Online Web Map and Feature Services	The system utilizes AGOL basemap and feature services to populate the web mapping application with spatial data
Web AppBuilder	The system was created with custom tools and layout
Data Upload	The system shall allow users with administrative permissions ability to upload individual OG shapefiles under 200mb in under 60 seconds

3.3 System Design

A system design was created to meet the needs of the client. This consisted of several components. The first was the compilation of several datasets from various sources into a standardized Esri file geodatabase. Spatial analysis could then be run using a combination of ArcGIS Spatial Analyst tools and the Cova (1999) risk methodology. This information was then pushed up to the cloud, and imported into a web mapping application using ArcGIS Web AppBuilder and ArcGIS Online. The client is then able to view and import data (Figure 3-1).

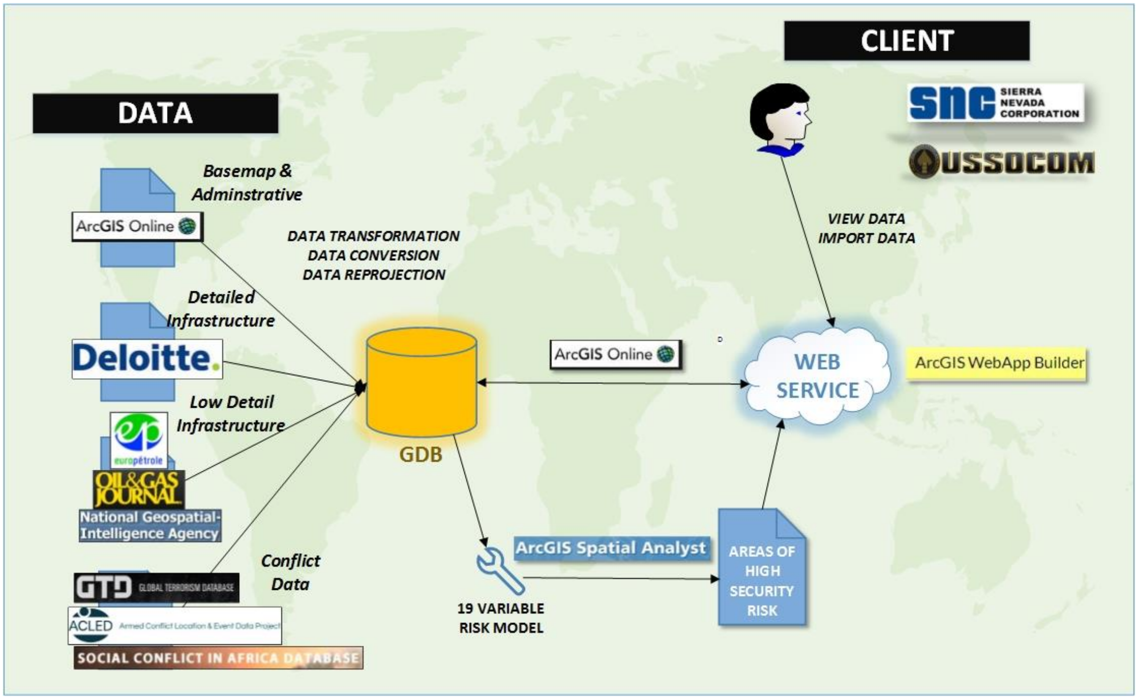


Figure 3-1: System architecture and components.

Data were separated into four major groups:

- Basemap and administrative layers
- Detailed infrastructure layers
- Low detail infrastructure
- Conflict data (for verification of risk model)
-

Once this information was assembled, data transformation, conversion, and re-projection were performed. A standardized, normalized Esri ArcGIS geodatabase was produced. This geodatabase, along with the risk theory model explained in Chapter 2, was used as the engine to drive the spatial analysis. A 19 variable risk model was used to produce several output layers and maps highlighting areas of high hazard, high vulnerability, and high risk. These were imported and stylized into an AGOL organizational account web-map. From here, other OG infrastructure layers were imported and stylized accordingly. Esri's Web AppBuilder was then used to pull the existing web map and its data into a customized interface suitable for client viewing. The client will be able to import its own data by logging into AGOL (credentials were provided to specific individuals) and uploading a variety of file formats (e.g., zipped shapefiles, excel, feature classes, etc.).

3.4 Project Plan

In order to produce an effective solution for the client, several project phases were completed. This high-level workflow is shown in sequential order (Figure 3-2).

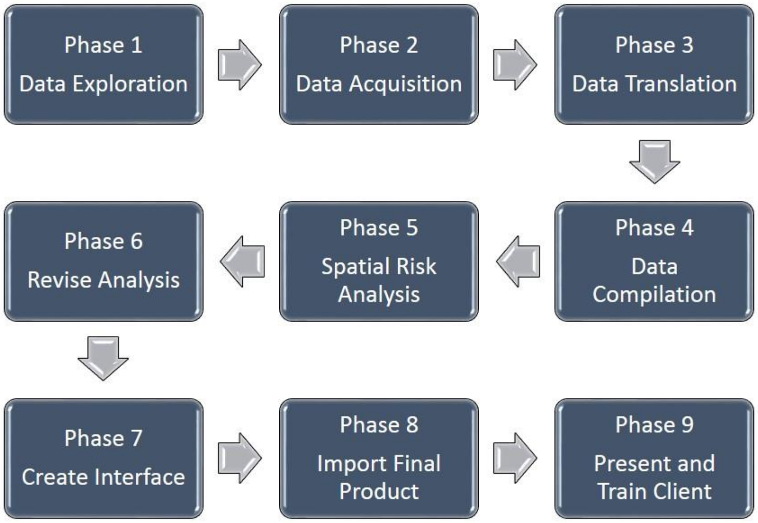


Figure 3-2: Basic system workflow.

The first step was to identify several data vendors and request pricing information for different datasets. The information was presented to the client in a specific format (free vs. non-free datasets in an excel spreadsheet). The contractor and client then came to an agreement on a preferred data vendor. This vendor was contacted and payment was scheduled. After the data acquisition phase, the data translation and compilation phases took place. Microsoft Excel and ArcGIS were used to clean and assemble the data into a standardized Esri ArcGIS Geodatabase for the client. At this time, spatial risk analysis research and subsequent analysis took place (the initial data purchased for the project arrived on May 20, 2014). After this, spatial analysis was re-run and outputs were generated. After creating a standard web-mapping interface, the final product import was able to take place. Training and presentation to the client occurred soon after.

A project plan was devised in late December, 2013, to identify specific project phases and tasks. Resources and time were allocated to each task of the project in hopes that the proposed plan would follow closely with reality (Table 4).

Table 4. Proposed detailed project schedule from December 2013

Task Name	Duration	Start	Finish
1 Phase #1 - Geodatabase Creation	**46 days**	**12/1/2013**	**1/31/2014**
1.1. Source Data	10 days	12/2/2013	12/13/2013
1.2. XMAS Holidays - Workload Reduced	14 days	12/16/2013	1/2/2014
1.3. Contact Data Providers	3 days	1/3/2014	1/7/2014
1.4. Sort Data into 2 Classes - Free vs Non Free	1 days	1/8/2014	1/8/2014
1.5. Client Approval and Sign Off	1 days	1/9/2014	1/9/2014
1.6. Acquire Data	2 days	1/10/2014	1/13/2014
1.7. Data Standardization	8 days	1/14/2014	1/23/2014
1.8. Massage Data into ESRI Petroleum Data	2 days	1/24/2014	1/27/2014
1.9. Clean/Scrub Data	3 days	1/28/2014	1/30/2014
1.10. Client Approval and Sign off	1 days	1/31/2014	1/31/2014
2 Phase #2 - Identify High Risk Areas	**42 days**	**2/1/2014**	**3/31/2014**
2.1. Identify Possible Data Sources from Phase1	3 days	2/3/2014	2/5/2014
2.2. Contact Client Regarding Criteria	3 days	2/6/2014	2/10/2014
2.3. Determine Appropriate Spatial Method	5 days	2/11/2014	2/17/2014
2.4. Perform Spatial Analysis and Create Output	10 days	2/18/2014	3/3/2014
2.5. Create Output Layers	9 days	3/4/2014	3/14/2014
2.6. Import and Theme Layers in AGOL	5 days	3/17/2014	3/21/2014
2.7. Client Approval and Sign-Off	1 days	3/24/2014	3/24/2014
2.8. Buffer Window	5 days	3/25/2014	3/31/2014
3 Phase#3 - Web Map w Data Uploading	**66 days**	**4/1/2014**	**7/1/2014**
3.1. Determine Appropriate Viewer	4 days	4/1/2014	4/4/2014
3.2. Build/Import Widgets	15 days	4/7/2014	4/25/2014
3.3. Spring Holiday Break	21 days	4/28/2014	5/26/2014
3.4. Develop QA/QC Prior to Testing	4 days	5/27/2014	5/30/2014
3.5. Feedback Webinar	1 days	6/2/2014	6/2/2014
3.6. General Client Testing at Clients HQ	1 days	6/3/2014	6/3/2014
3.7. Data Upload Testing at Clients HQ	2 days	6/4/2014	6/5/2014
3.8. Training Webinar	2 days	6/6/2014	6/9/2014
3.9. Client Approval and Sign-Off	1 days	6/10/2014	6/10/2014
3.10. Hand Over AGOL Admin Rights	2 days	6/11/2014	6/12/2014
3.11. Produce Training Doc for Client	2 days	6/13/2014	6/16/2014
3.12. Buffer Window	10 days	6/17/2014	6/30/2014

Over the course of the project, the timeline changed significantly. This mostly revolved around a delay in data acquisition. Several steps were taken to prevent this issue from causing serious harm to the project schedule. The first was a mitigation plan, which entailed beginning the data acquisition process early on in the project. This helped provide more time for acquisition to take place when delays did occur. The second was identifying a trigger point at which a contingency plan would take place. In this case, if data were not acquired by February 28, 2014, the contingency plan was utilized. This meant that additional free data would be acquired and imported into a geodatabase for processing. This process was implemented on March 1, 2014, in response to unexpected delays in acquisition of the proposed dataset from Deloitte. Data were acquired from several sources and compiled into a geodatabase for use in modelling risk. Other than this setback, the timeline fell according to plan. A client needs assessment was conducted throughout the lifecycle of the project. By May 20, 2014, data acquisition of both the contingency and original datasets was completed. The identification of high-risk areas was completed by July 15, 2014. The completion and hosting of the web map on University of Redlands servers was concluded June 1, 2014 (~3 months allocated). It is important to note that no data were created or digitized. This costly and exhaustive process was not the focus of this project. Both the initial and revised timelines associated with the project are included below (Figure 3-3).

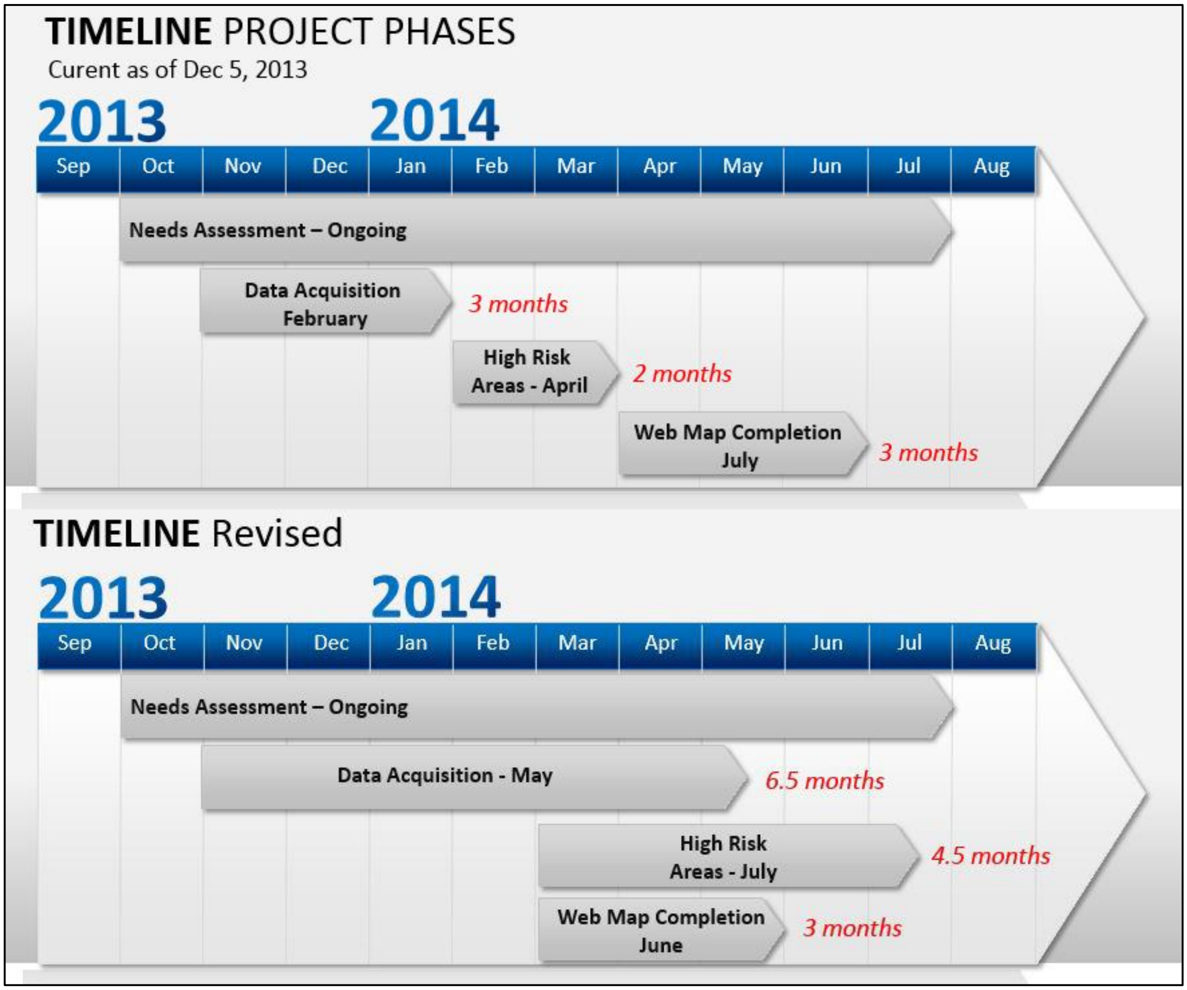


Figure 3-3: Initial and revised timeline.

3.5 Summary

This section went into detail on the system analysis and design component of the project. Identifying functional and non-functional requirements, scheduling, workflow, and system design were just some of the factors discussed. Several lessons were learned regarding timeline and schedule. The first was that data acquisition can often be a lengthy process. This was dealt with by implementing mitigation and contingency plans that prevent this issue from affecting the overall success of the project. Acquiring independent datasets early in the project lifecycle also helps. It was the application of these strategies that ensured this project was completed on time and on budget, and at the same time ensuring the client’s requirements were met.

Chapter 4 – Database Design

To perform reliable GIS analysis, a solid database foundation is required. Several components contribute to a solid foundation. The first is a sound conceptual model for the project, which is discussed in Section 4.1. Section 4.2 discusses the logical model. Section 4.3 looks at sources for the data used in the project. Section 4.4 discusses data collection methods. Section 4.5 goes into detail on any data scrubbing and loading that took place prior to analysis.

4.1 Conceptual Data Model

There are many factors that can determine the vulnerability of oil & gas infrastructure to attack/theft. Many of these are very difficult to capture in a GIS database (for example socio-political and economic variables such as government policies or economic ties). Others lend themselves well to GIS analysis including existing location of pipelines, refineries, and wells. Nineteen variables were captured in the conceptual data model for this project. These variables were split into three major groups. The first were natural hazard layers. These contain information regarding the natural environment such as the proximity to geological areas and the location of existing offshore and onshore OG deposits. The second group was technological hazard layers. These consist of existing infrastructure from the built environment such as pipelines, wells, refineries, LNG terminals, and other facilities. These two groups comprised the hazard layers on which an associate risk model was based. The third group of layers captured in the database were vulnerability layers. These were associated with human influence. Variables such as proximity to urban areas, roads, and previous history of OG infrastructure attacks were modeled. These variables required some processing in order to be modeled correctly in the database. Once this process occurred, a vulnerability model was produced. A subsequent risk model, vulnerability map, hazard map, and risk map were derived from these datasets. Figure 4-1 illustrates the entities and relationships described above.

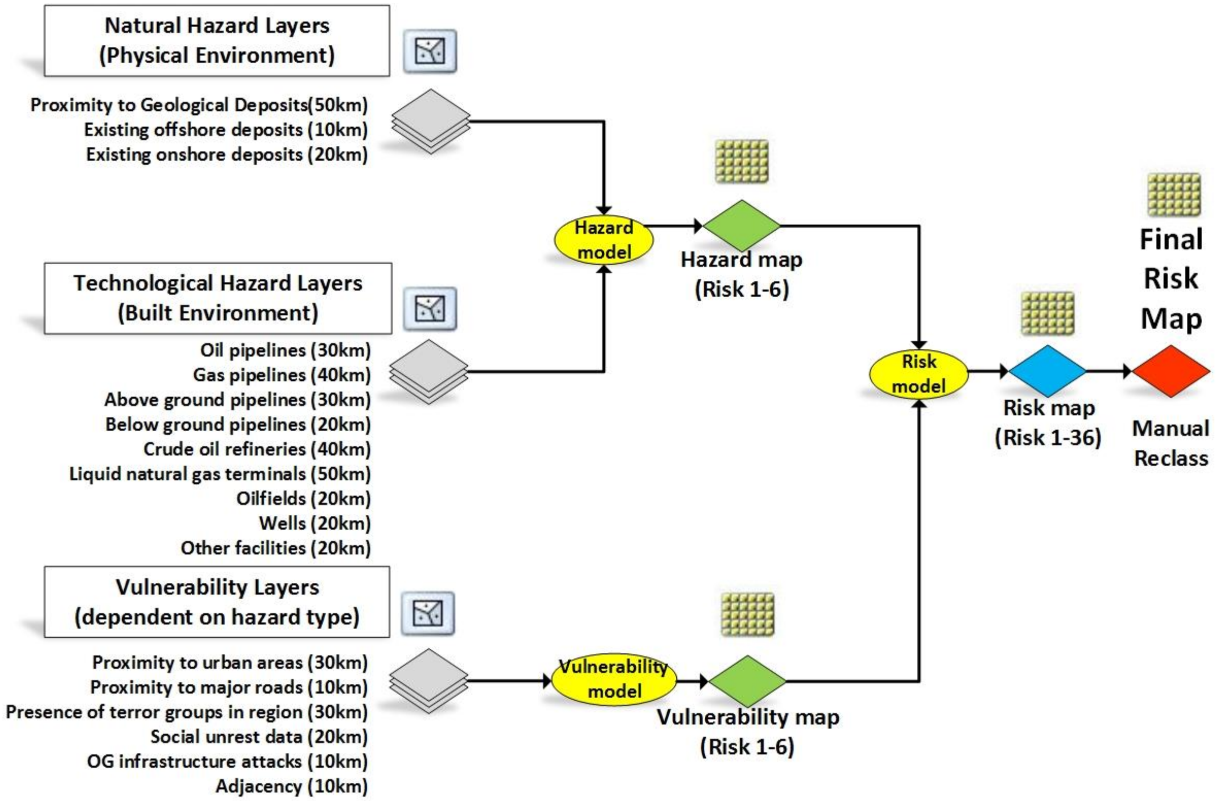


Figure 4-1: Conceptual data model.

4.2 Logical Data Model

There were several datasets used in the creation of a logical data model. The administration feature dataset contained feature classes important for reference, as well as inputs used to generate the risk output maps. The OG conflict feature dataset contained several point files useful in the verification process of the model. The exploration and production feature dataset contained layers relevant to that industry. Similar for the infrastructure feature dataset. The population and transportation feature dataset also contained layers useful as inputs used to generate the risk output maps. The Deloitte data feature dataset contained highly detailed and accurate layers obtained from Deloitte Group via purchase. These layers were for specific areas in Southern Mozambique and Northern Algeria because the cost for the entire country of Algeria and Mozambique was too great for the client. These layers were also useful for verification purposes by running the existing model on more detailed, accurate data. Lastly, the raster datasets were primarily the outputs generated by the previously discussed feature datasets. Among the features not listed in Figure 4-2 for visualization reasons, a large number of temporary layers were generated in two separate feature datasets called Analysis and Detailed Analysis. These stored provisional layers such as results from buffers, clips, merges, and dissolves that were necessary to derive the final output maps. The Analysis feature dataset stored the temporary layers from the low-scale risk model outputs generated for the continent of Africa, and the Analysis Detail feature dataset stored the outputs generated for the detailed analysis of risk performed for the countries of Mozambique and Algeria. Figure 4-2 illustrates the logical data model for the key datasets used in the project.

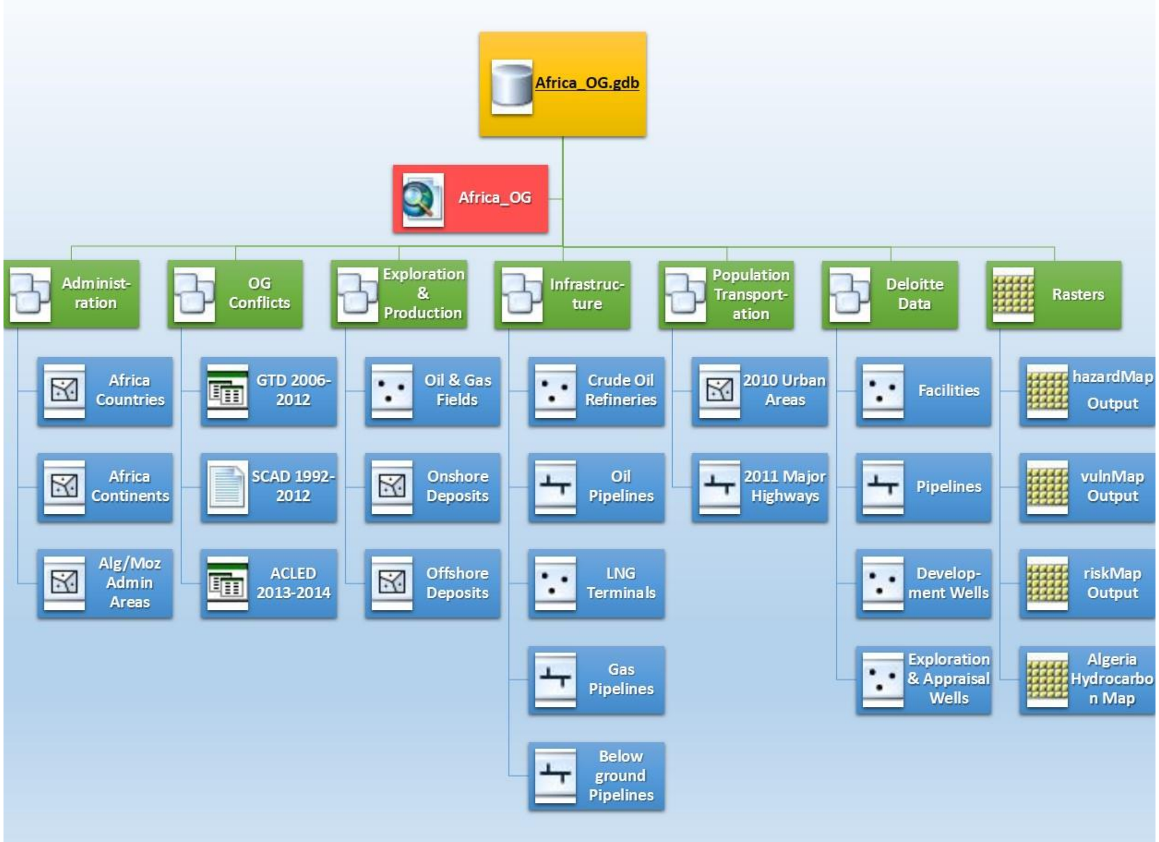


Figure 4-2: Logical data model.

4.3 Data Sources

The data for this project came from a variety of sources. There were four primary data types acquired. The first were basemap and administrative layers. The basemaps for this project were pulled from ArcGIS Online (AGOL). The user has the ability to select different basemaps (e.g. satellite, roads, etc.) hosted by AGOL. Administrative layers (e.g. continents, countries, major roads) were obtained from Esri's 2013 data that comes with ArcGIS 10.2. The second class of data is low-detail infrastructure data, primarily useful for continental or individual country level analysis. These data were obtained from several free sources online including Europetrole, *The Oil & Gas Journal*, and the National Geospatial Intelligence Agency. The third class of data was highly detailed infrastructure data purchased from Deloitte Group on May 20, 2014, useful for individual country or state/provincial level analysis. This information could be considered more reliable because in many cases it is more accurate and is updated monthly. It also contains proper metadata and attribute information. The last type of data was conflict data. This information contained conflict locations in Africa for several pre-defined periods. This information was acquired from three sources and was filtered to include only OG data on the continent of Africa. More information on this process can be found in Section 4.5. The first was the Global Terrorism Database (GTD). This contains information on terrorist attacks from 2006-2013. The second was the Social Conflict in Africa Database (SCAD). This contains information on social conflicts from 1992-2012. The last was the Armed Conflict Location and Event Data Project (ACLED). This contains information on political violence in developing states from 2013-2014. Table 4 illustrates the Master Data List used for the project.

Table 5. Master data list

ID	Name	File Type	Source	Link	Formatting/Scrubbing Required?	Vintage
1	AGOL Basemap	Map Service	Esri AGOL	http://www.esri.com/software/arcgis/arcgisonline	No	2014
2	Esri Administrative Layers (continents, countries, roads)	GDB feature classes	Esri	Esri 10.2 download	Yes	2011 and 2012
3	Crude Oil Refineries	Shapefile	Harvard World Map	http://worldmap.harvard.edu/maps/oilandgasmap	Yes	2006
4	Liquid Natural Gas Terminals	Shapefile	EuroPetrole	http://www.euro-petrole.com/ac_01_index.php	Yes	N/A
5	Oil Pipelines	Shapefile	Harvard World Map	http://worldmap.harvard.edu/maps/oilandgasmap	Yes	N/A
6	Gas Pipelines	Shapefile	Harvard World Map & ENTSOG	http://worldmap.harvard.edu/maps/oilandgasmap http://www.entsog.eu/	Yes	N/A
7	Oil & Gas Pipelines	Shapefile	NGA (Formerly NIMA)	http://egsc.usgs.gov/nimamaps/	Yes	N/A

8	Oilfields	Shapefile	NGA (Formerly NIMA)	http://egsc.usgs.gov/nimamaps/	Yes	1998
9	Offshore & Onshore Deposits	Shapefile	PRIO Journal of Peace Research	http://www.prio.org/Data/Geographical-and-Resource-Datasets/Petroleum-Dataset/Petroleum-Dataset-v-12/	Yes	2007
10	Algeria Hydrocarbon Map	GeoTIFF	Harvard World Map	worldmap.harvard.edu/maps/oilandgasmappipelin	No	N/A
11	North Algeria Facilities, Pipelines, Wells (at cost)	Shapefile	Deloitte Group	http://www.psg.deloitte.com/productspetroview.asp	No	May 2014
12	South Mozambique Facilities, Pipelines, Wells (at cost)	Shapefile	Deloitte Group	http://www.psg.deloitte.com/productspetroview.asp	No	May 2014
13	2006-2012 Terrorist attacks GTD	.dbf	Global Terrorism Database	http://www.start.umd.edu/gtd/contact/	Yes	2014
14	2013-2014 Political Violence ACLED	.dbf	Armed Conflict & Location Event DB	http://www.acleddata.com/data/	Yes	2014
15	1990-2012 Social Conflict in Africa DB SCAD	.dbf	Social Conflict in Africa DB	https://www.strausscenter.org/scad.html	Yes	2014

4.4 Data Collection Methods

One of the primary goals of this project was data collection. After determining the client had little spatial data available, a decision was made to start assembling information from a variety of sources. These sources were categorized into two main groups: free and for sale. After discovering and downloading all possible free datasets, maps were delivered to the client and a discussion took place in January 2014 regarding these maps. During this meeting, the client and contractor agreed that the existing data were not sufficient for the client's requirements. They were of low detail and in many cases incomplete. The data also were not current and missing attribute and metadata information. The client and contractor agreed that a budget would need to be incorporated for data acquisition. The contractor approached several OG data vendors, assembled pricing information, and presented the list of potential vendors to the client. The costs for data ranged from $5,000-$25,000 USD for detailed information for single countries, and up to $300,000 USD for regions of Africa, for example Sub-Saharan Africa. Upon review of the data sources presented, the client and contractor agreed to use the client's pre-specified budget for this project to select the winning quote from Deloitte Consulting Group out of the United Kingdom. The dataset purchased consisted of shapefiles for pre-selected regions of Algeria and Mozambique. Data included both on and offshore OG infrastructure, such as wells, pipelines, and facilities data including refineries and LNG terminals (Figure 4-3).

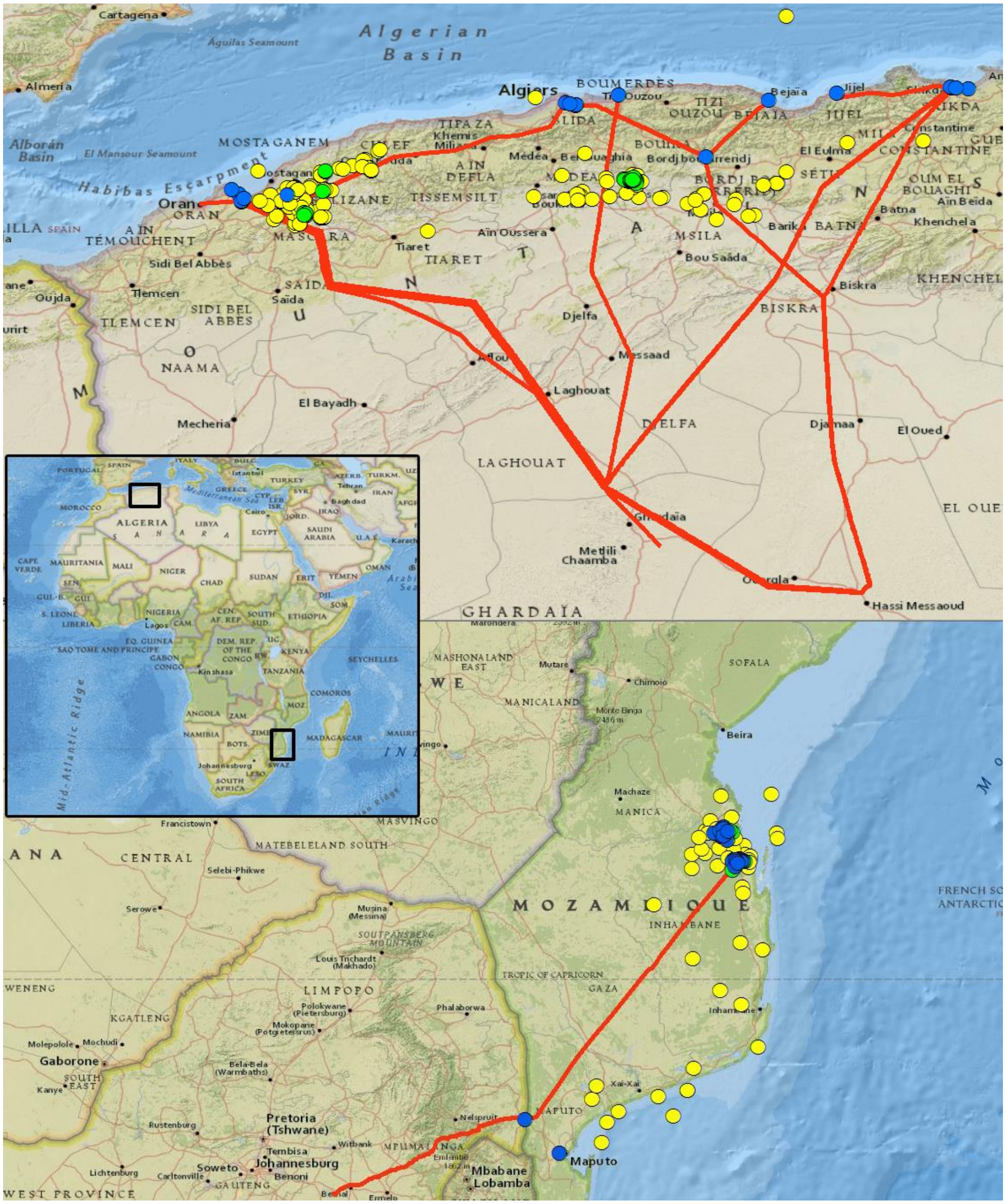


Figure 4-3: Pipeline, well, and facilities data acquired from Deloitte Group.

These features were selected because they were the most frequently targeted in Africa for oil theft and terrorist attack. Approximately 40 hours were spent on data acquisition.

Prior to implementation, the features from the conceptual model had to be transferred into a logical data model. This consisted of several tasks. The first was the download of each individual dataset and conversion into shapefile format. From here, an ArcGIS file Geodatabase (Africa_OG.gdb) was designed that would contain several feature datasets. Within each feature dataset, relevant layers were re-projected into the

WGS84 coordinate system. After this, each dataset was converted and imported into feature class format. These datasets were the basis for the primary raster outputs of the model (hazardMap, vulnerabilityMap, and riskMap) which were stored in the database and not in any particular feature dataset. A separate raster basemap for Algeria displaying detailed OG information was also included with the other rasters.

4.5 Data Scrubbing and Loading

Three primary software packages were used to scrub and load the data: Esri ArcMap, Esri ArcCatalog, and Microsoft Excel. Several steps were taken in the creation of the Esri Geodatabase for the client. The first was to create the geodatabase (Africa_OG.gdb) in ArcCatalog. Specific feature datasets were then created to store each individual feature class. Eight primary feature datasets were created:

- *Administration*, for administrative layers such as countries and continents;
- *Analysis*, for all analysis work;
- *Conflicts*, conflict point data extracted from MS excel database files and imported as feature classes into the geodatabase;
- *Electrical*, the client was moderately interested in electrical information as well as OG;
- *ExplorationProduction*, for exploration information such as existing wells, deposits, OG basins, and other upstream OG data;
- *Infrastructure*, the primary feature dataset for this project, containing midstream and downstream OG data such as refineries, LNG terminals, pipelines, and other facilities;
- *Population,* containing 2010 populated areas;
- *Transportation*, containing 2011 road centerlines; and
- *Raster* with information such as the Algeria Hydrocarbons Map and outputs from the risk model (hazardMap, vulnerabilityMap, riskMap)

All datasets were re-projected into the WGS84 coordinate system, which allowed for standardization among data. All individual feature layers were imported into their corresponding dataset feature dataset. This coordinate system was chosen because it is a standard global coordinate system suitable for performing large scale analysis. It is also accepted by ArcGIS Online, which would be required at future stages of the project. After this, a feature class of the continent of Africa was extracted using the Selection tool in ArcMap. For this new feature class, all subsequent data layers were clipped using the Clip tool to the boundary of Africa, the intended study area. Subsequently, each individual feature class was “scrubbed.” This entailed ensuring all fields had legible field names and attribute information. Any redundant or irrelevant fields were deleted. The LNG terminal data from Europetrole had attribute data in French. This was translated to English prior to import into the geodatabase. All metadata and source information for each layer was inputted manually. This will allow users to locate the most recent copy of the data for future projects.

4.6 Summary

There are many factors that come into play when attempting to predict where future OG infrastructure attacks may occur. Many of these factors are difficult to model in a GIS. However, several lend themselves well to GIS mapping. This project consumed close to 19 GIS layers that were stored in a geodatabase. This chapter discussed the database design used for the project. It included components on the conceptual and logical data models implemented, as well as sections on data sources, collection methods, and scrubbing/loading the data into an Esri geodatabase. Chapter 5 will discuss how this database was utilized to implement a GIS solution for the client.

Chapter 5 – Implementation

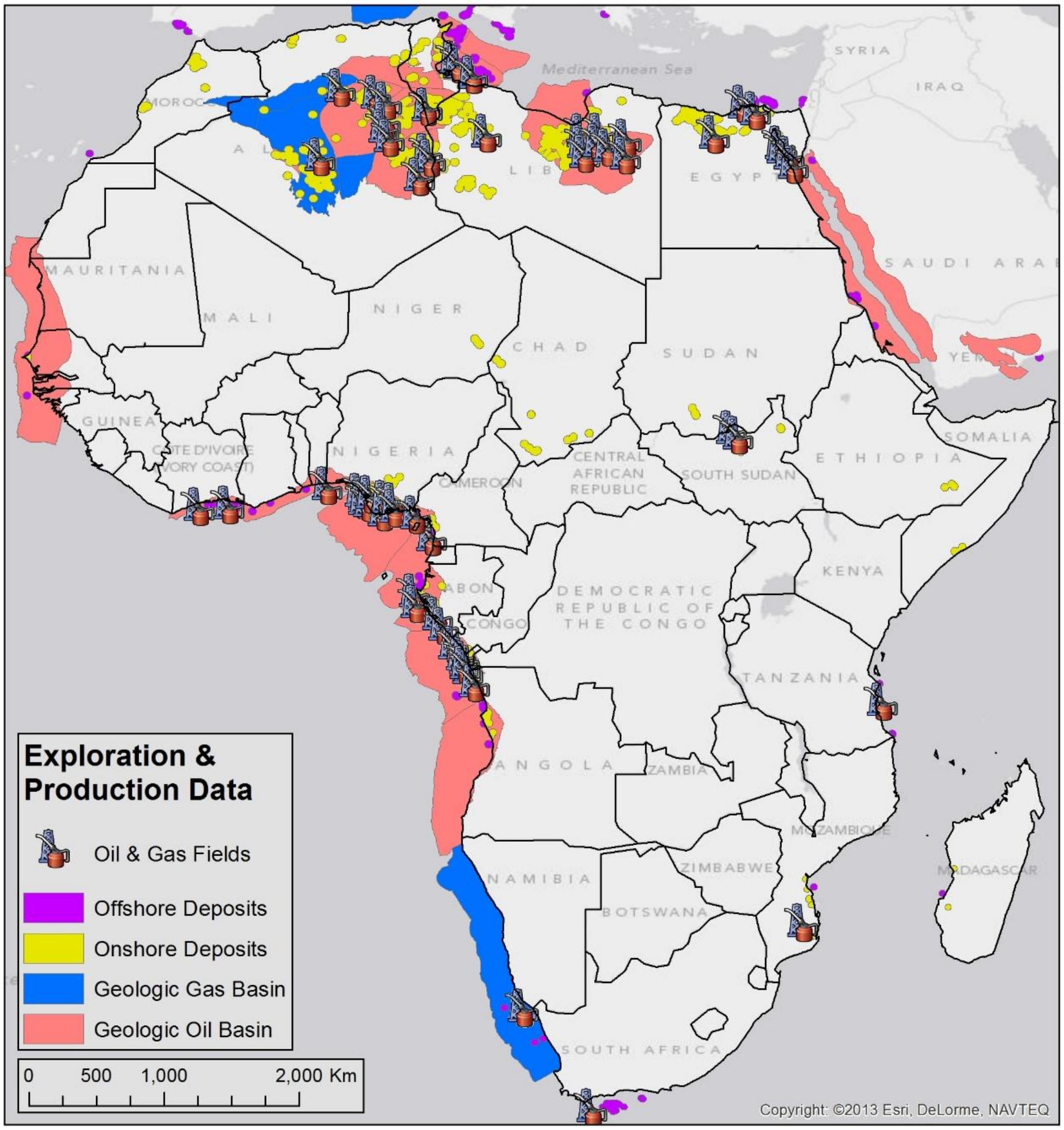
The implementation phase of this project consisted of three components. The first was the spatial analysis model that identified areas of high and low risk. Several ArcMap tools were used in conjunction with the ArcMap Spatial Analyst tools in order to produce hazard, vulnerability, and risk maps. The second component was the acquisition and translation of verification data used to determine the accuracy of the model. This was completed using keyword searches in Microsoft Excel to first filter the data, and by using ArcMap's Extract Values to Points tool to determine the accuracy of the model. The third component was the creation of the web mapping application. This was constructed using an ArcGIS Online organizational account with the beta version of Esri Web AppBuilder, and was hosted on the University of Redlands public webserver.

5.1 Spatial Analysis of Risk

A theoretical model and formula were required in order to identify high and low risk areas. Cova's (1999) risk model was selected. In this model, risk is a combination of all elements of hazard and vulnerability. This equation is found in its most basic form below (Equation 5.1).

$$Risk = R(H(E_h),V(E_v)) \qquad \textbf{Equation 5.1}$$

In this equation, hazard is a function H of the hazard of elements of E_h; vulnerability is a function V of the vulnerability of elements E_v ; and risk is a function R of the results of the hazard and vulnerability functions (Cova, 1999). All variables were directly or indirectly captured in ArcMap 10.2 using spatial datasets acquired from various data providers. In order to produce the hazard model, exploration and production (EP) and infrastructure layers were utilized. Maps displaying these data for the continent of Africa are found below (Figures 5-1 and 5-2).



Copyright: ©2013 Esri, DeLorme, NAVTEQ

Figure 5-1: EP data used in the risk model to produce the Hazard variable.

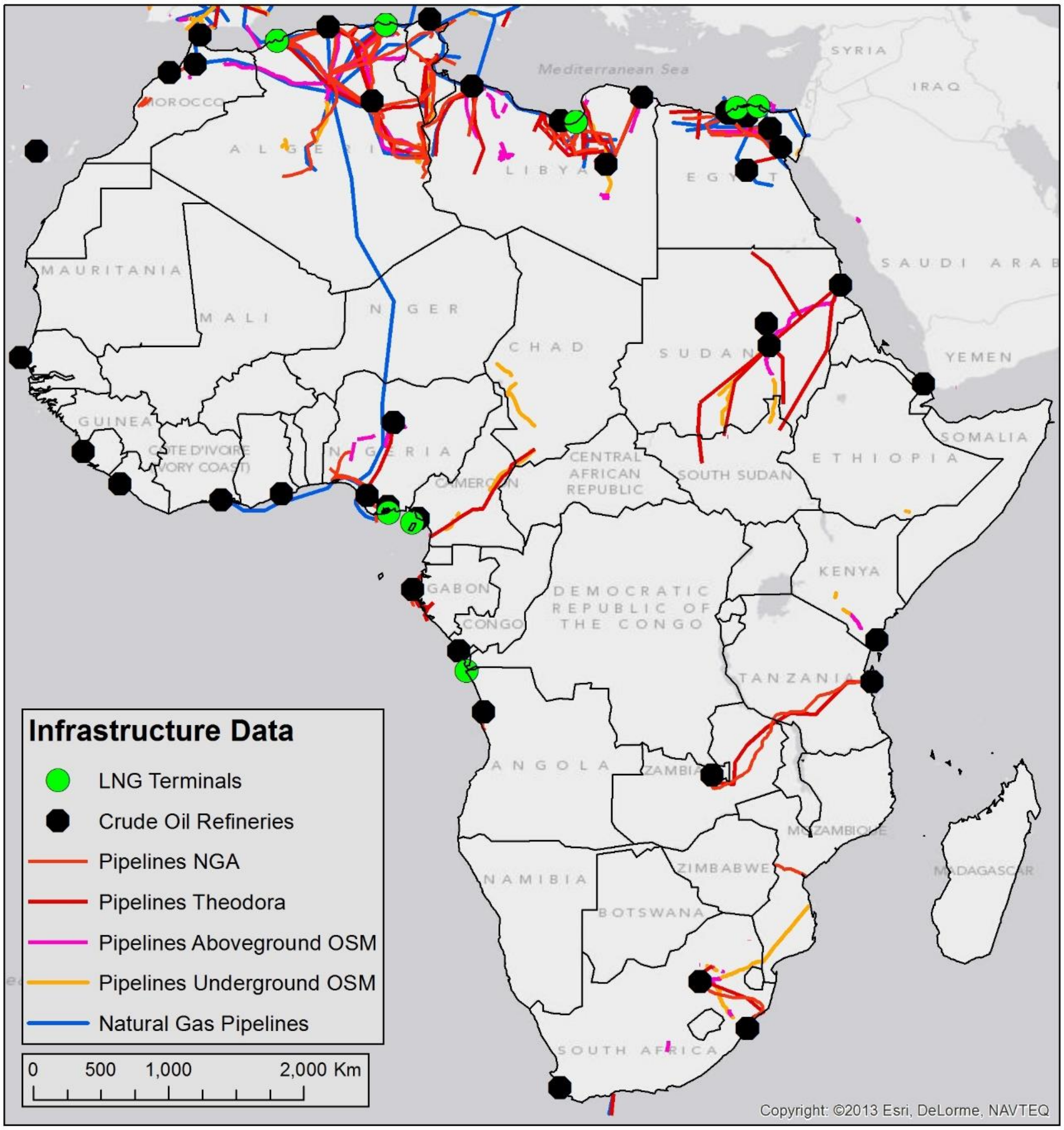
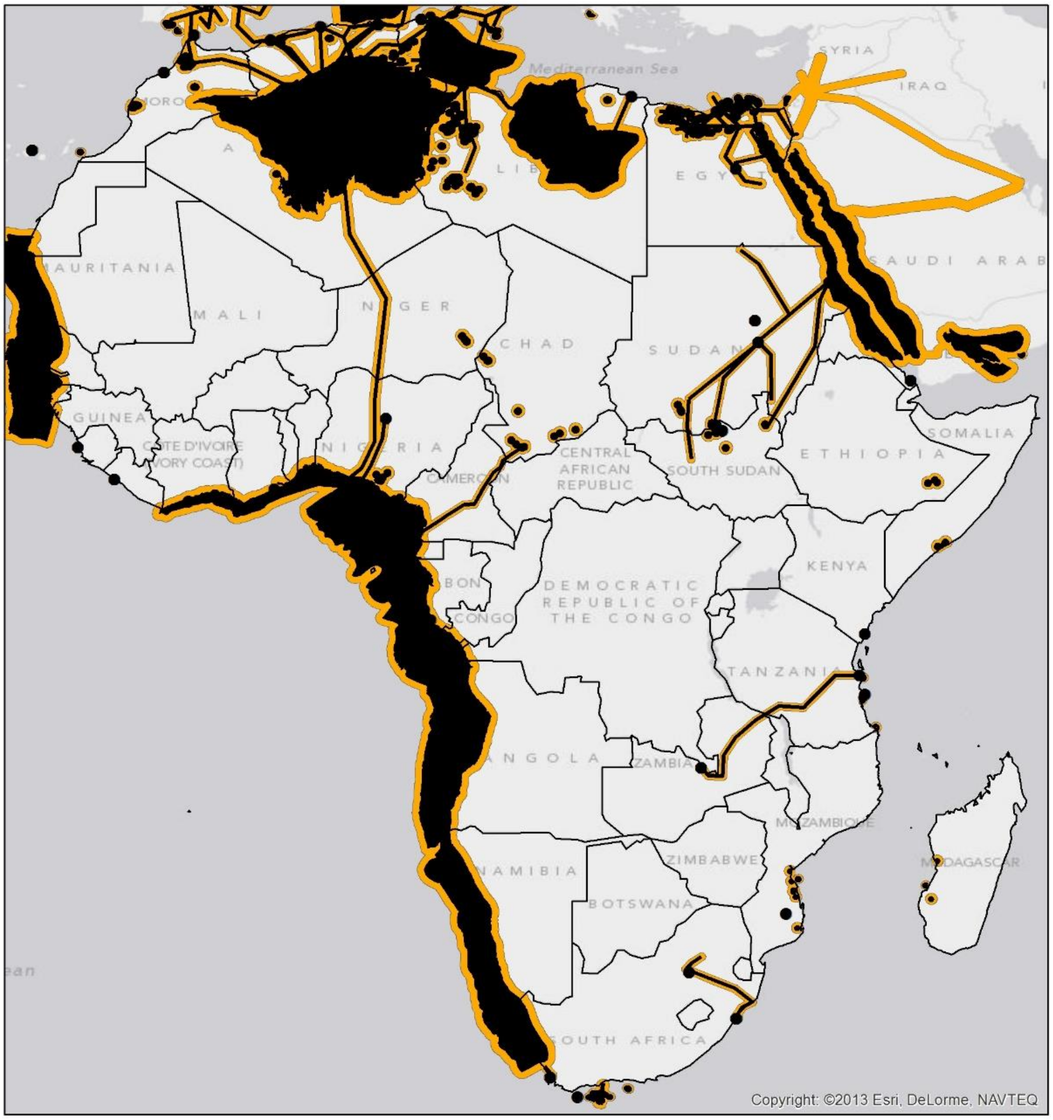


Figure 5-2: Data used in the risk model to produce the Hazard variable.

A buffer for each individual layer (from 10-50 kilometers) within the exploration and production and infrastructure datasets was produced using the Buffer tool. The proximity to coast layer required the use of the Multi-Part to Single-Part tool in order to prepare the data for manual selection. After this, each layer was merged into one layer using the Merge tool and dissolved using the Dissolve tool. Merged infrastructure and EP information are shown below in black, and the final setbacks are displayed in orange (Figure 5-3).



Copyright: ©2013 Esri, DeLorme, NAVTEQ

Figure 5-3: Buffers performed on existing EP/Infrastructure data.

The Multiple-Ring Buffer tool was used on these setbacks at intervals of 50, 100, 150, and 200, and 250 km respectively. This transformed the setbacks from non-contiguous vector information to a semi-continuous vector surface. This was a requirement in the construction of a raster surface. After generating the multi-ring buffers, the Multi-Part to Single-Part tool was used to split the data up into separate geometries, from which the Select tool was used to assign integer values of 1-5 to each individual polygon using the Add Field tool. The Clip tool was then used to clip the extent of the setbacks to the Africa continent boundary. Figure 5-4 illustrates red areas that were considered high risk for hazard, because they are found in close proximity to the inputs (in black). Lighter red or white areas were considered low risk.

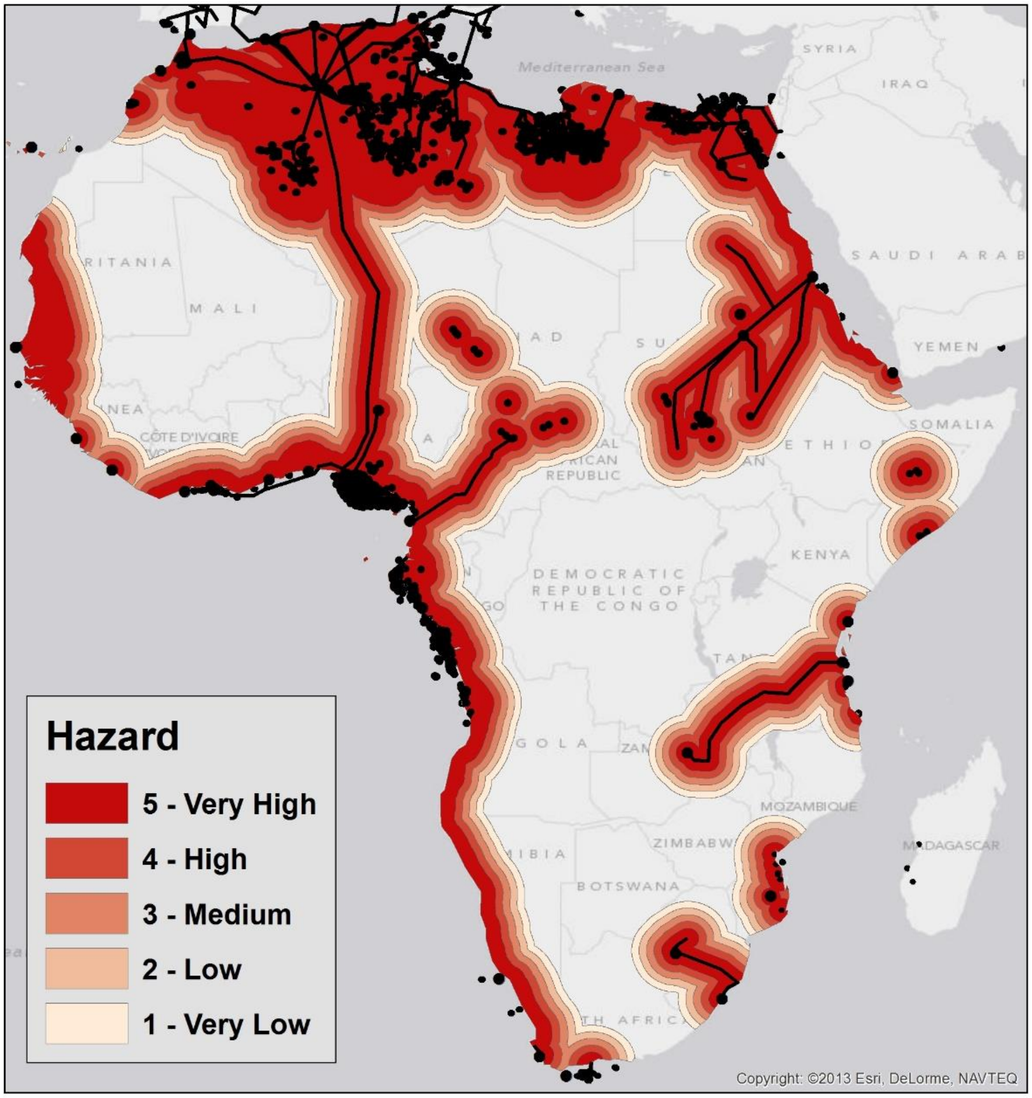
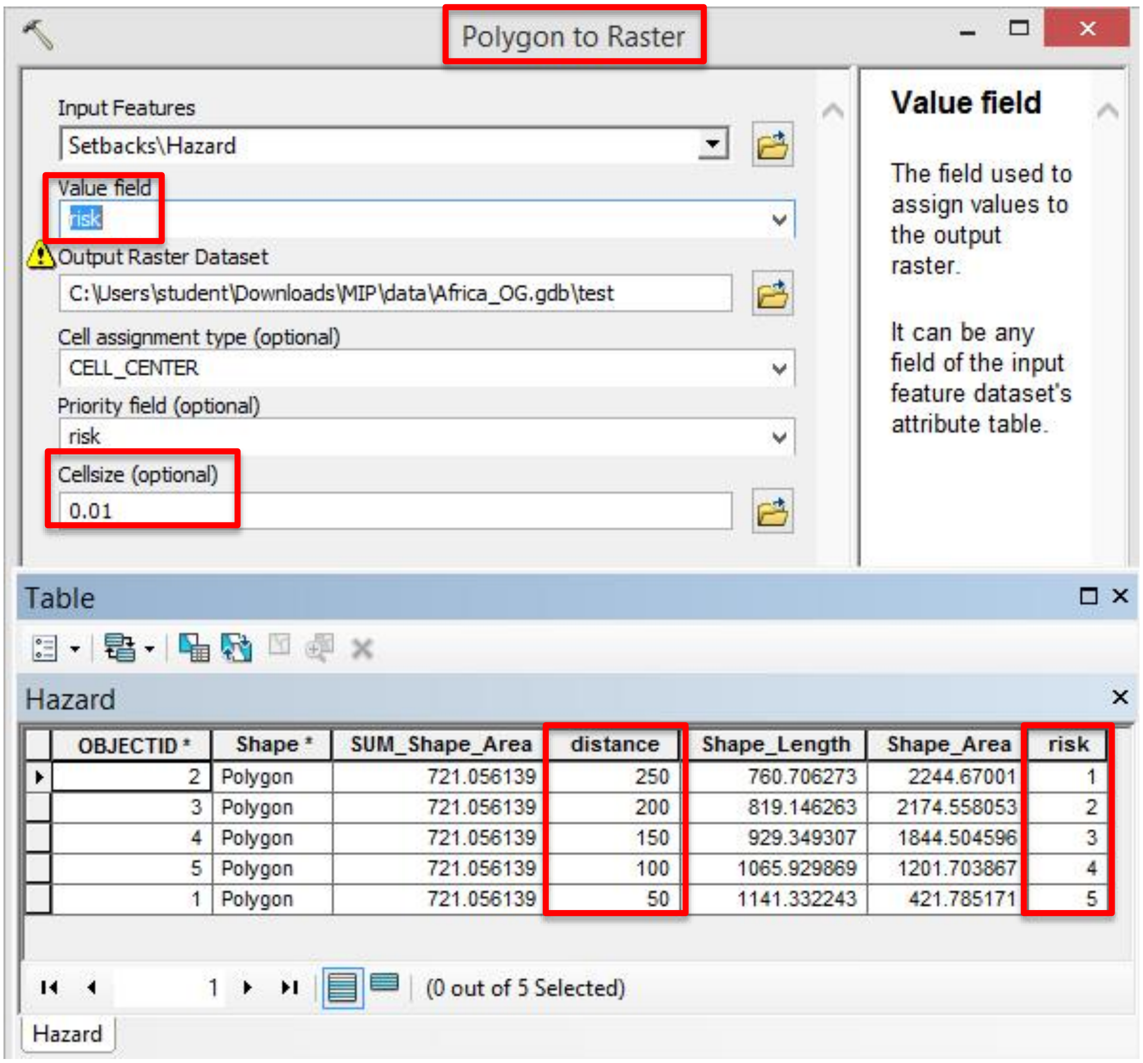


Figure 5-4: Polygon buffers surrounding existing EP/infrastructure data.

The Polygon to Raster tool was then utilized to create a continuous raster surface from which additional analysis could be performed. The risk field was used to transform the polygons to raster values from 1 to 5. A cell size of 0.01 decimal degrees was selected (Figure 5-5).



Input Features: Setbacks\Hazard

Value field: risk

Output Raster Dataset: C:\Users\student\Downloads\MIP\data\Africa_OG.gdb\test

Cell assignment type (optional): CELL_CENTER

Priority field (optional): risk

Cellsize (optional): 0.01

Value field

The field used to assign values to the output raster.

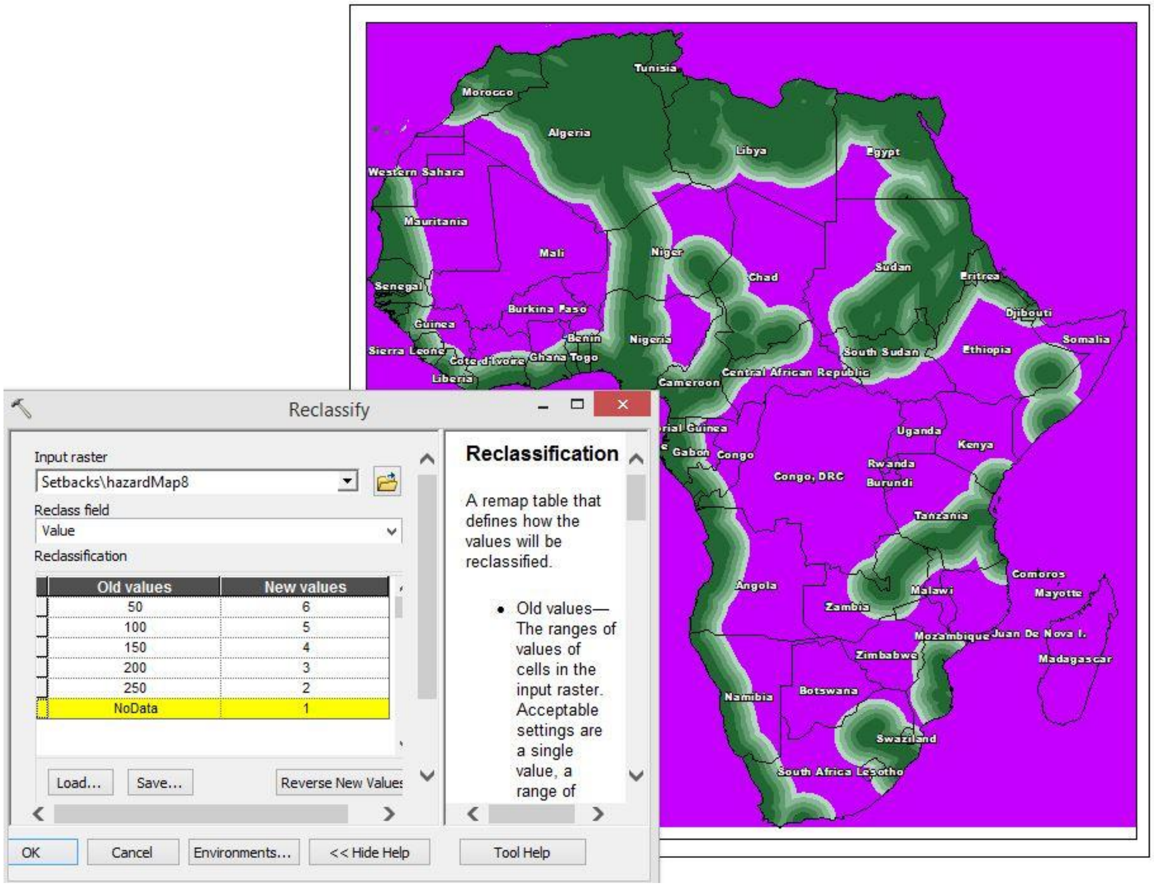
It can be any field of the input feature dataset's attribute table.

OBJECTID *	Shape *	SUM_Shape_Area	distance	Shape_Length	Shape_Area	risk
2	Polygon	721.056139	250	760.706273	2244.67001	1
3	Polygon	721.056139	200	819.146263	2174.558053	2
4	Polygon	721.056139	150	929.349307	1844.504596	3
5	Polygon	721.056139	100	1065.929869	1201.703867	4
1	Polygon	721.056139	50	1141.332243	421.785171	5

(0 out of 5 Selected)

Figure 5-5: Conversion from polygon to raster.

The last step was to add an additional risk category for null values. This allowed for risk value to be assigned to the entire continent of Africa and was required to yield significant results. If null values or holes are present in the data, when hazard is multiplied by vulnerability, null or zero values will result. As such, the hazard raster was reclassified to include a sixth value for risk (Figure 5-6). The purple areas are the 6th class, which were assigned a low hazard equal to one. Each additional hazard class was reclassified up one value.



Input raster: Setbacks\hazardMap8

Reclass field: Value

Reclassification

Old values	New values
50	6
100	5
150	4
200	3
250	2
NoData	1

Reclassification

A remap table that defines how the values will be reclassified.

- Old values—The ranges of values of cells in the input raster. Acceptable settings are a single value, a range of

Figure 5-6: Reclassification of 5 class hazard raster to 6 classes

A generalized workflow describing the process for creating the hazard map is shown below (Figure 5-7).

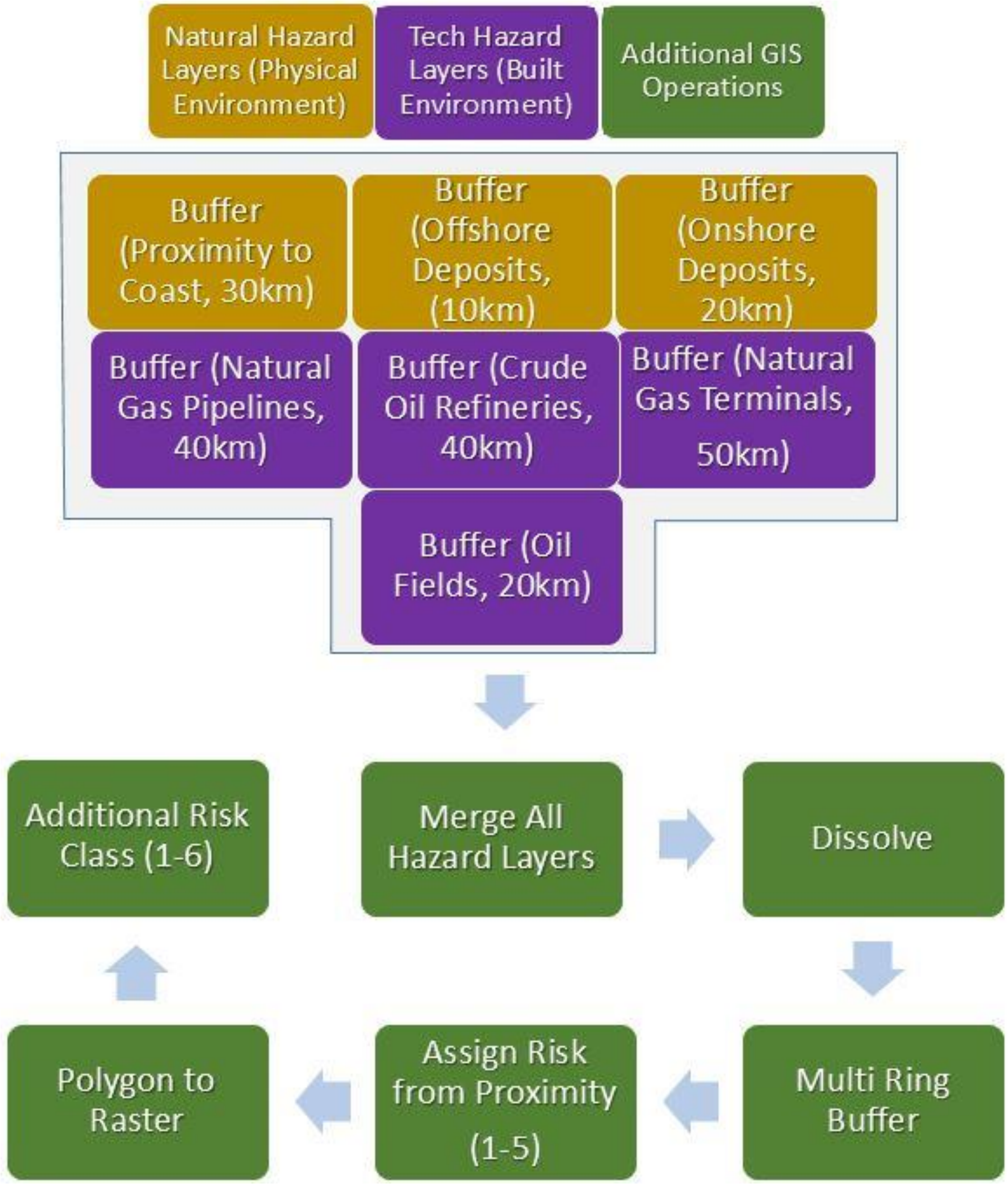


Figure 5-7: Workflow showing process used to create the hazard map

The next step was to conduct the geographic analyses required for vulnerability. This involved using several variables from the human environment for inputs such as proximity to major population centers, proximity to major roads, and historical social conflict events. A 2010 urban areas layer and 2011 major roads layer were used as inputs (Figure 5-8). In addition, three separate conflict databases were acquired that identify social conflict and terrorist activity (Figure 5-9). The first is the Global Terrorism Database (GTD) from the period of 2006 to 2012. This project is an open-source database at the University of Maryland that includes information on terrorist events around the world. The second is the Armed Conflict and Location Event Database (ACLED) from 2014. This project is a comprehensive public collection of political violence data for developing states. The last is the Social Conflict in Africa Database (SCAD) from 1992-2012. This project is administered by the Robert R. Strauss center for international security and law at the University of Texas at Austin. It includes protests, riots, strikes, inter-communal conflict and government violence against civilians. In total there are 16,056 records.

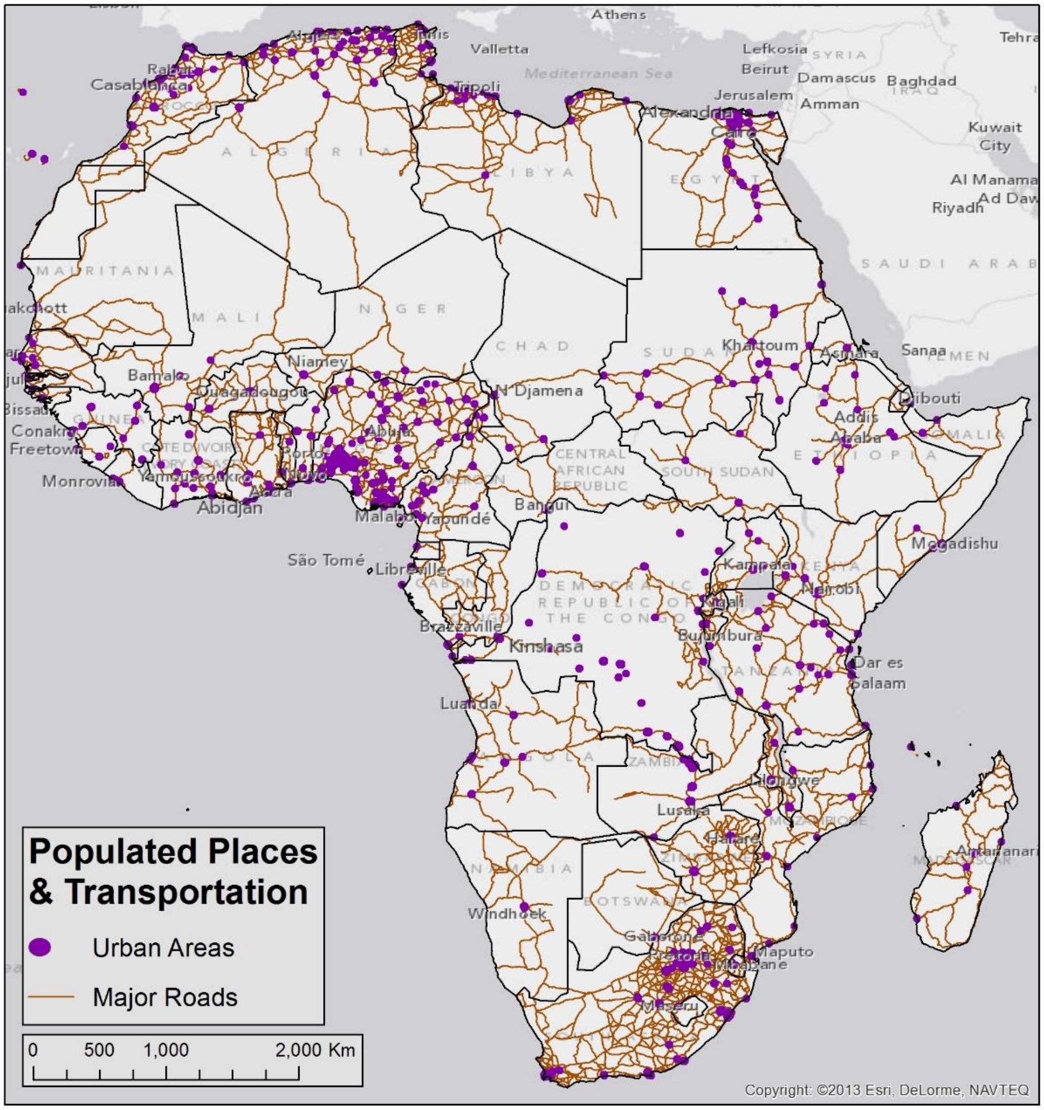


Figure 5-8: Datasets used in the risk model to produce vulnerability

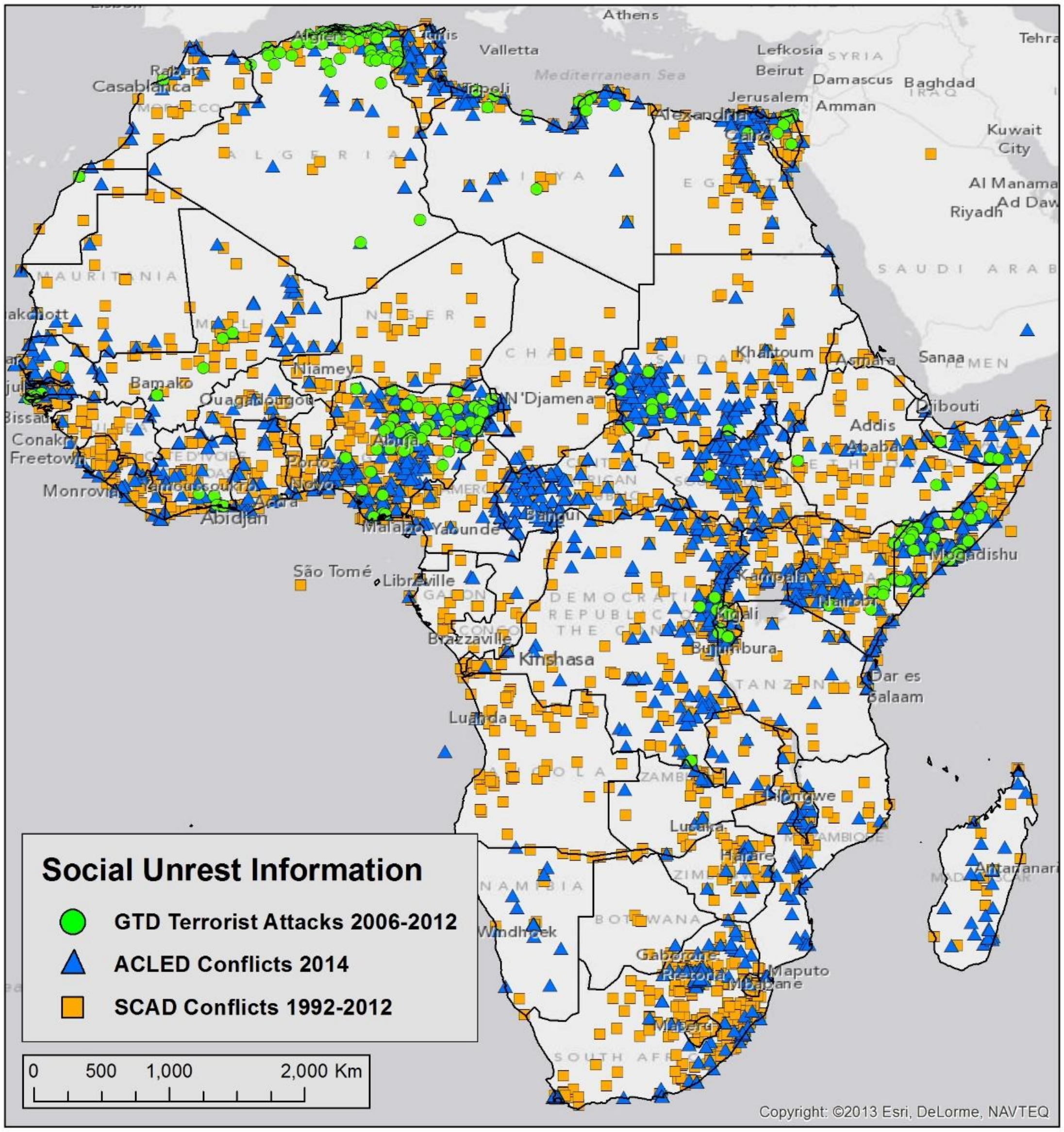
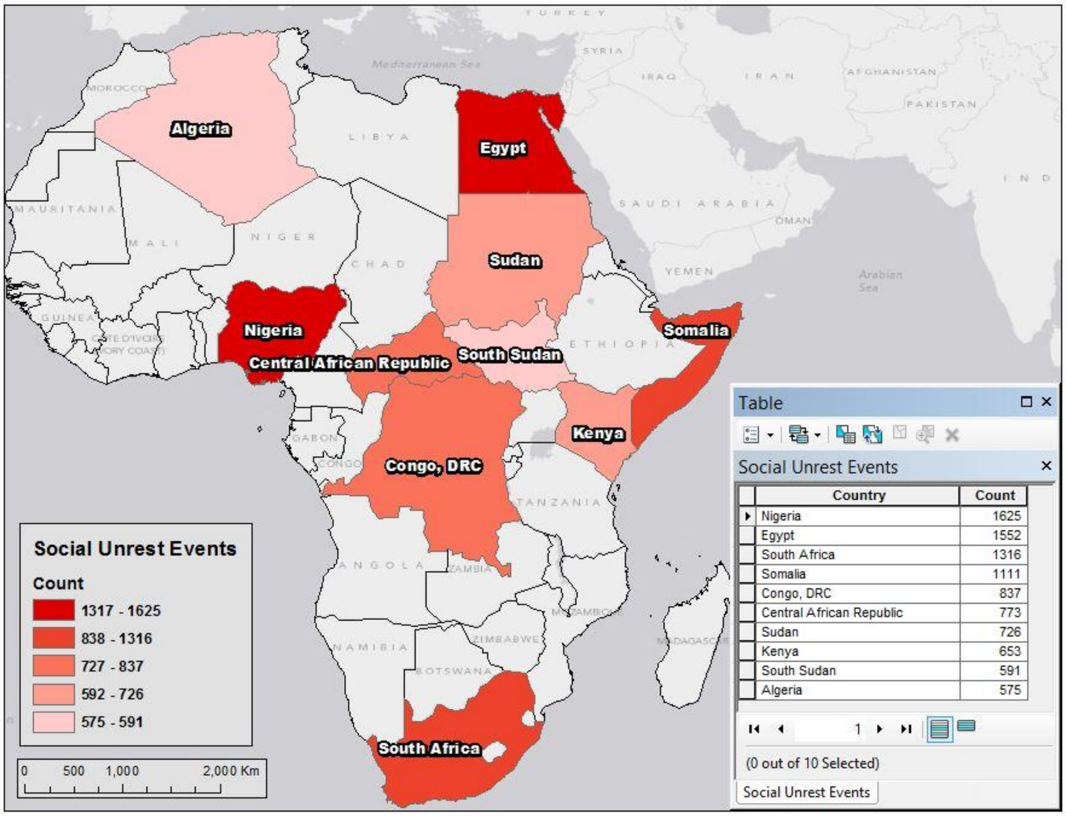


Figure 5-9: Datasets used in the risk model to produce vulnerability

Many of the same GIS operations used to produce the hazard map, such as buffers, clips, merges, and dissolves were also used to produce the vulnerability map (see Chapter 6). Buffers on populated areas and major highways were conducted. A spatial join was used on the conflict data in conjunction with the Count tool to produce a new layer called the Top 10 for social unrest (Figure 5-10). The countries highlighted in pink and red have had the most occurrences of terrorist attacks and conflicts from 1992-2014. A table in the bottom right shows these top 10 countries organized by number of attacks/conflict (Figure 5-10).



Country	Count
Nigeria	1625
Egypt	1552
South Africa	1316
Somalia	1111
Congo, DRC	837
Central African Republic	773
Sudan	726
Kenya	653
South Sudan	591
Algeria	575

Figure 5-10: The Top 10 countries for terrorist attacks and social unrest

The next step was to take the existing conflict information and filter it into attacks/theft on oil and gas infrastructure using multiple keyword searches (see Section 5.2). The resulting .xls file was imported into ArcMap 10.2 displaying oil and gas attacks from 1992 to 2012. Using a visual inspection, a new layer was derived from this information called the “Top 7” oil and gas infrastructure incident countries. These countries were also selected because of high numbers of oil and gas infrastructure attacks/theft both on and offshore (Table 6). Somalia was included in the “Top 7” because of its high levels of social unrest, public unrest, and its recent discovery of proven natural gas reserves (Central Intelligence Agency). Sudan was included in the “Top 7” because of its high levels of social unrest and presence of existing oil and gas infrastructure and deposits.

Table 6. Raw count of numbers of events located within each country

Country	**Infrastructure attack/theft events**
Nigeria	85
Egypt	17
Algeria	13
Libya	9
South Sudan	4
Sudan	3
Somalia	3
Angola	2
Ethiopia	1
Togo	1
Tunisia	1
South Africa	1
Gabon	1
Congo	1
Ghana	1
Guinea	1
Democratic Republic of Congo	1

The top 7 countries were exported into a new geodatabase feature class. Adjacency was the next geographic variable to be modeled. Using a Euclidian distance setback of 350 km, adjacent areas were buffered and a new feature class was created (Figure 5-11). This distance was chosen because it accounts for the large discrepancy in size between many of the countries on the continent of Africa. It allows countries such as Togo, Ghana, and Benin to be included, while at the same time allowing for the Northeast portion of the Democratic Republic of Congo to be included. Both the Top 7 and adjacent areas were given relevant weights based on their proximity to conflict occurrences. Purple points are oil and gas infrastructure attacks from 1992 to 2014, yellow areas are countries where attacks are common, and green polygons are areas physically adjacent to those countries.

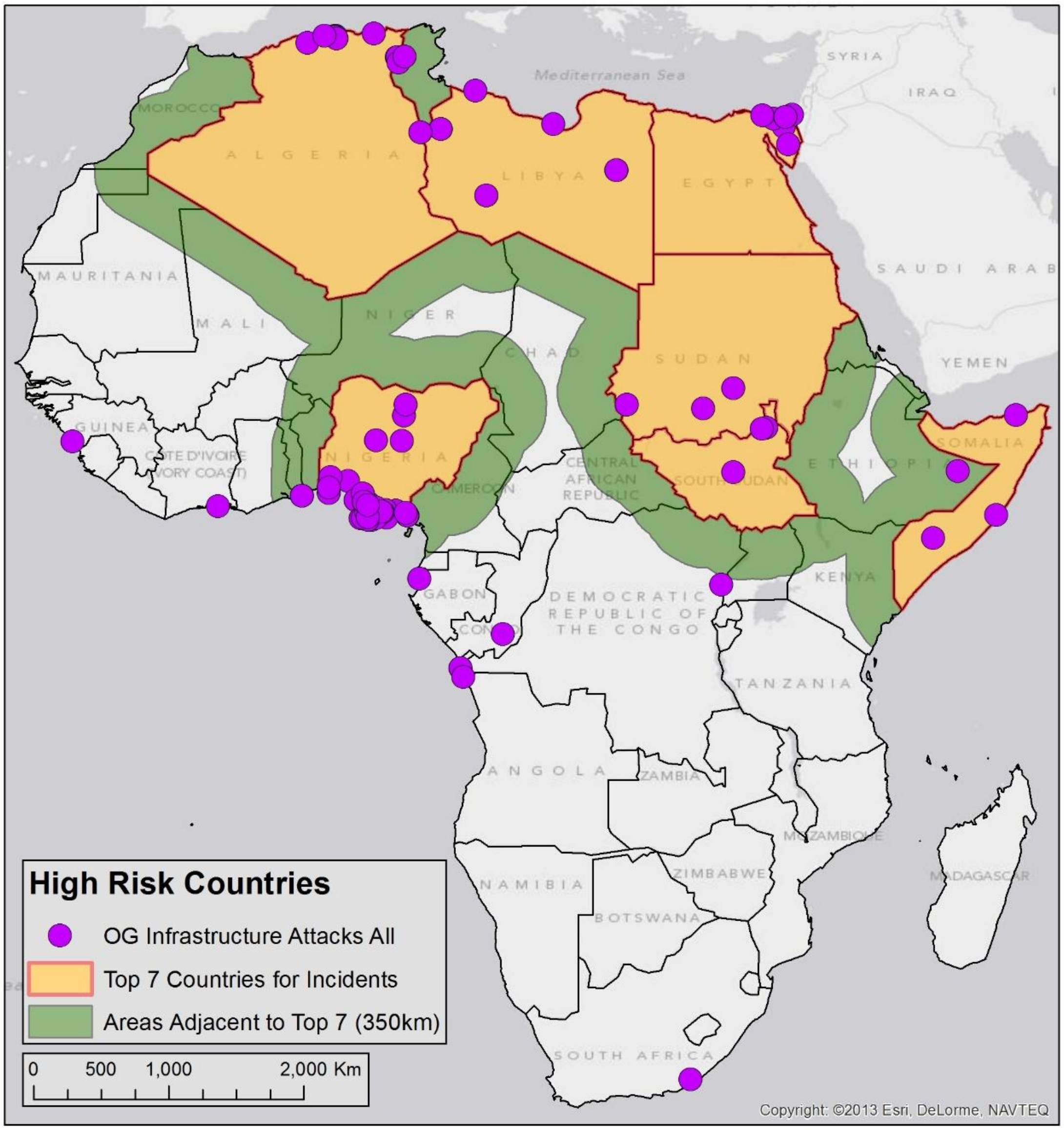


Figure 5-11: High-risk OG target countries and their adjacent areas

After Buffer, Merge, Clip, Dissolve, and Multiple-Ring Buffer tools were run, a polygon output was generated representing vulnerability. In order to speed up the processing time for the Polygon to Raster tool (0.01 decimal degrees cell size), the Smooth tool was used to generalize the geometries for the polygon. A polygon vulnerability map was generated in which dark red areas represent high vulnerability, while light pink and white areas represent low vulnerability. Populated areas and major highway infrastructure are shown in black (Figure 5-12).

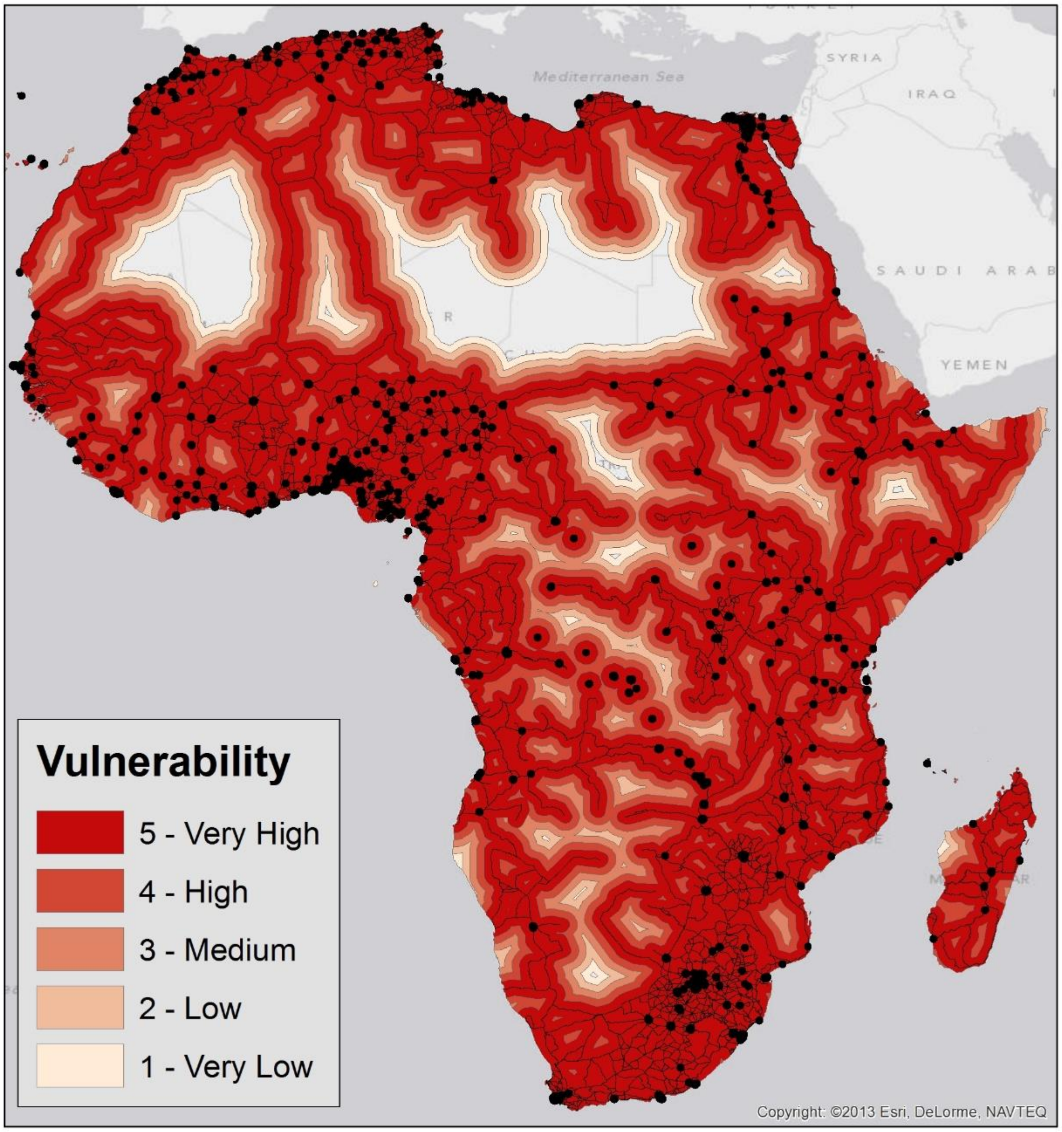


Figure 5-12: Polygon buffers surrounding populated areas and major highways

The Sort tool was used to sort the polygon values from lowest to highest. The Polygon to Raster tool was then used to convert the polygons to raster values from 1-5. The Reclassify tool was then used to add an additional raster value in order to fill in the holes in the raster, in the same process used in the creation of the hazard map (see Figure 5-6). A generalized workflow showing the operations used to create the vulnerability map can be found below (Figure 5-13).

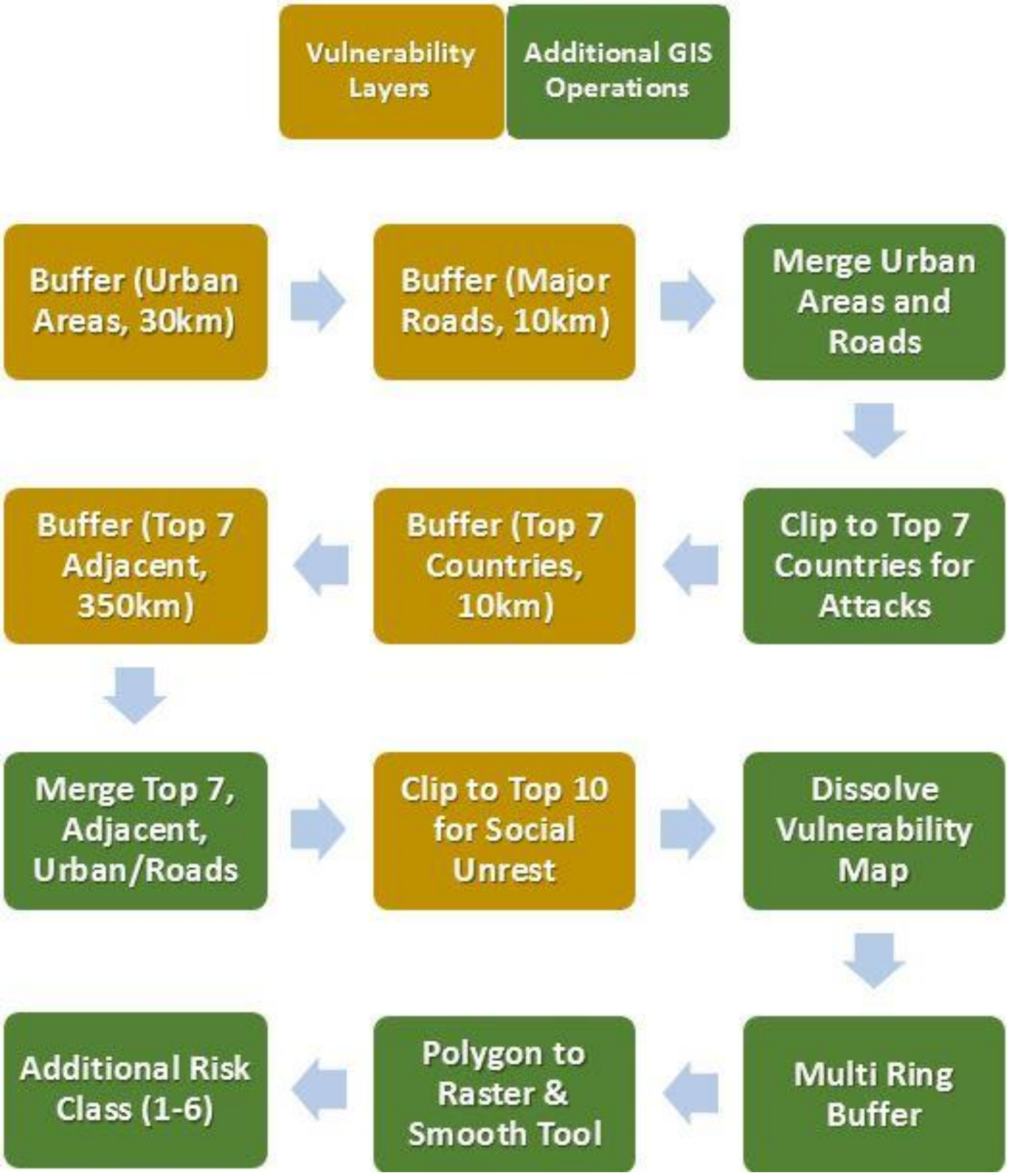
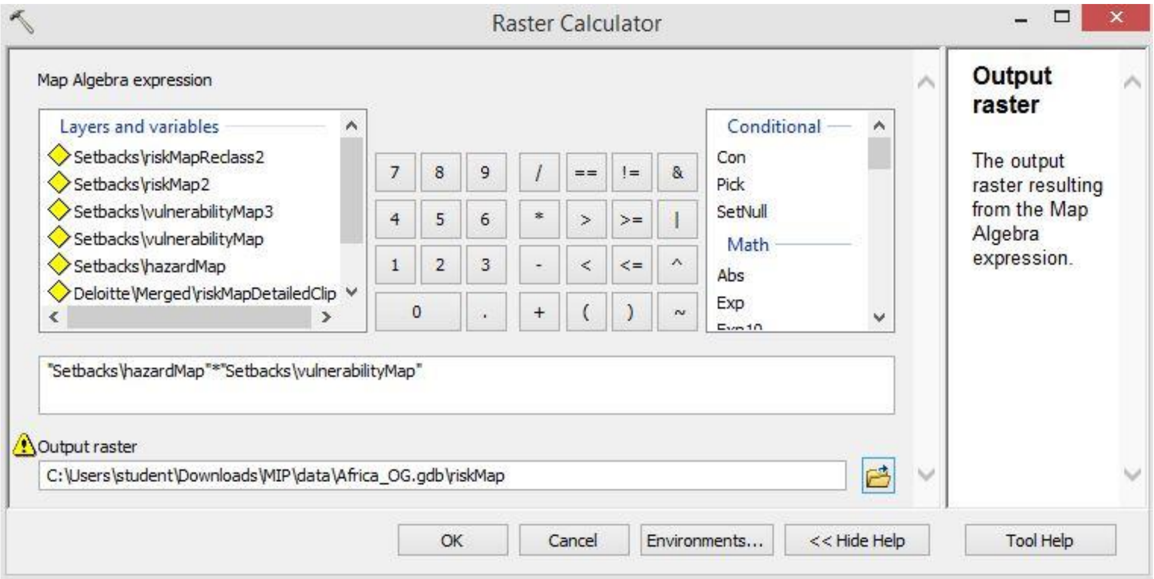


Figure 5-13: Workflow showing process used to create the vulnerability map

The last major step took the raster for vulnerability and raster for hazard and multiplied them together using the Raster Calculator tool from the ArcGIS Spatial Analyst toolbar and map algebra (Figure 5-14).



"Setbacks\hazardMap"*"Setbacks\vulnerabilityMap"

Output raster
C:\Users\student\Downloads\MIP\data\Africa_OG.gdb\riskMap

Output raster

The output raster resulting from the Map Algebra expression.

Figure 5-14: Map algebra using the Raster Calculator tool

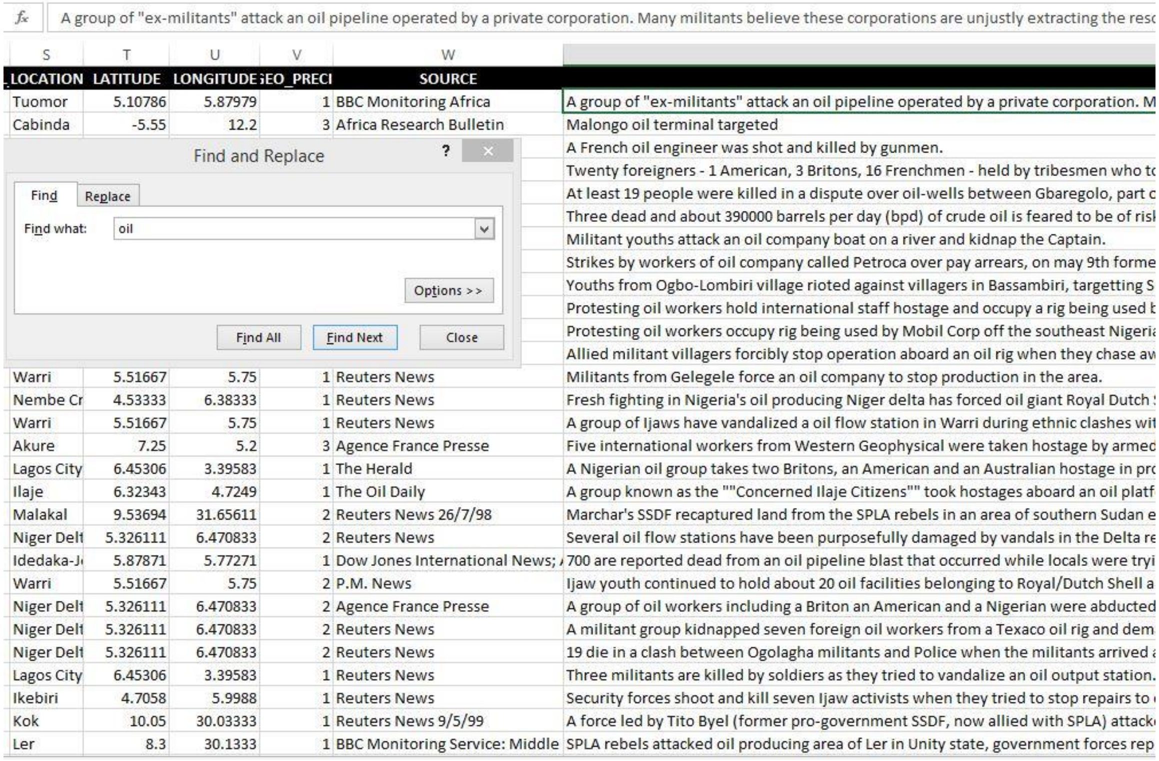
A manual classification scheme was applied to the result. The output will be discussed in Chapter 6. A workflow of the process described throughout Section 5.1 can be found in Appendix A.

5.2 Risk Model Verification

In order to better understand the spatial risk analysis model created, the results needed to be quantified. There were two primary steps in this process. Comparing the model accuracy to a set of completely independent OG infrastructure attacks was the most important one. In order to perform this step, data needed to be acquired and filtered. An Excel spreadsheet was acquired from the Armed Conflict Location and Event Data Project (ACLED) which contained a list of global conflict events from 1997 to 2012. Data were filtered to include only conflicts on the continent of Africa. In the same way, a keyword search was performed on the comments field to filter the conflicts to include only OG attack/theft events. The search was structured to contain the following keywords:

- Oil
- Gas
- Pipeline
- Petroleum
- LNG
- Energy

The results were inspected to ensure no duplicate records were present. Events that were of little importance to the project (e.g., protests outside of facilities for better working conditions) were removed. The final database consisted of 153 OG infrastructure attack events (1997 to 2012) The original database is found along with an example keyword search for “oil” (Figure 5-15).



A group of "ex-militants" attack an oil pipeline operated by a private corporation. Many militants believe these corporations are unjustly extracting the reso

Find what: oil

S	T	U	V	W	
LOCATION	LATITUDE	LONGITUDE	EO_PRECI	SOURCE	
Tuomor	5.10786	5.87979	1	BBC Monitoring Africa	A group of "ex-militants" attack an oil pipeline operated by a private corporation. M
Cabinda	-5.55	12.2	3	Africa Research Bulletin	Malongo oil terminal targeted
					A French oil engineer was shot and killed by gunmen.
					Twenty foreigners - 1 American, 3 Britons, 16 Frenchmen - held by tribesmen who to
					At least 19 people were killed in a dispute over oil-wells between Gbaregolo, part o
					Three dead and about 390000 barrels per day (bpd) of crude oil is feared to be of risk
					Militant youths attack an oil company boat on a river and kidnap the Captain.
					Strikes by workers of oil company called Petroca over pay arrears, on may 9th forme
					Youths from Ogbo-Lombiri village rioted against villagers in Bassambiri, targetting S
					Protesting oil workers hold international staff hostage and occupy a rig being used b
					Protesting oil workers occupy rig being used by Mobil Corp off the southeast Nigeria
					Allied militant villagers forcibly stop operation aboard an oil rig when they chase aw
Warri	5.51667	5.75	1	Reuters News	Militants from Gelegele force an oil company to stop production in the area.
Nembe Cr	4.53333	6.38333	1	Reuters News	Fresh fighting in Nigeria's oil producing Niger delta has forced oil giant Royal Dutch
Warri	5.51667	5.75	1	Reuters News	A group of Ijaws have vandalized a oil flow station in Warri during ethnic clashes wit
Akure	7.25	5.2	3	Agence France Presse	Five international workers from Western Geophysical were taken hostage by armed
Lagos City	6.45306	3.39583	1	The Herald	A Nigerian oil group takes two Britons, an American and an Australian hostage in pro
Ilaje	6.32343	4.7249	1	The Oil Daily	A group known as the ""Concerned Ilaje Citizens"" took hostages aboard an oil platf
Malakal	9.53694	31.65611	2	Reuters News 26/7/98	Marchar's SSDF recaptured land from the SPLA rebels in an area of southern Sudan e
Niger Delt	5.326111	6.470833	2	Reuters News	Several oil flow stations have been purposefully damaged by vandals in the Delta re
Idedaka-J	5.87871	5.77271	1	Dow Jones International News;	700 are reported dead from an oil pipeline blast that occurred while locals were tryi
Warri	5.51667	5.75	2	P.M. News	Ijaw youth continued to hold about 20 oil facilities belonging to Royal/Dutch Shell a
Niger Delt	5.326111	6.470833	2	Agence France Presse	A group of oil workers including a Briton an American and a Nigerian were abducted
Niger Delt	5.326111	6.470833	2	Reuters News	A militant group kidnapped seven foreign oil workers from a Texaco oil rig and dem
Niger Delt	5.326111	6.470833	2	Reuters News	19 die in a clash between Ogolagha militants and Police when the militants arrived
Lagos City	6.45306	3.39583	1	Reuters News	Three militants are killed by soldiers as they tried to vandalize an oil output station.
Ikebiri	4.7058	5.9988	1	Reuters News	Security forces shoot and kill seven Ijaw activists when they tried to stop repairs to
Kok	10.05	30.03333	1	Reuters News 9/5/99	A force led by Tito Byel (former pro-government SSDF, now allied with SPLA) attack
Ler	8.3	30.1333	1	BBC Monitoring Service: Middle	SPLA rebels attacked oil producing area of Ler in Unity state, government forces rep

Figure 5-15: “Oil” keyword filter on ACLED (1997-2012) conflict

Once the accurate locations of previous OG infrastructure attacks were included in the geodatabase, the accuracy of the model could be quantified. The point locations were overlaid over the final risk raster. The Extract Values to Points tool was used to extract the values of the raster into the point locations. The next step in the accuracy assessment was to account for the spatial phenomenon known as complete spatial randomness (CSR). This assumes that among a given number of points, an unspecified number will occur in a specified area due to randomness. So as to account for this phenomenon, the Create Random Points tool was used to create 128 random points on the continent of Africa. This was the same number of points that the true locations of oil and gas events contained (Figure 5-16). The results of this technique and a full accuracy assessment will be discussed in Chapter 6.

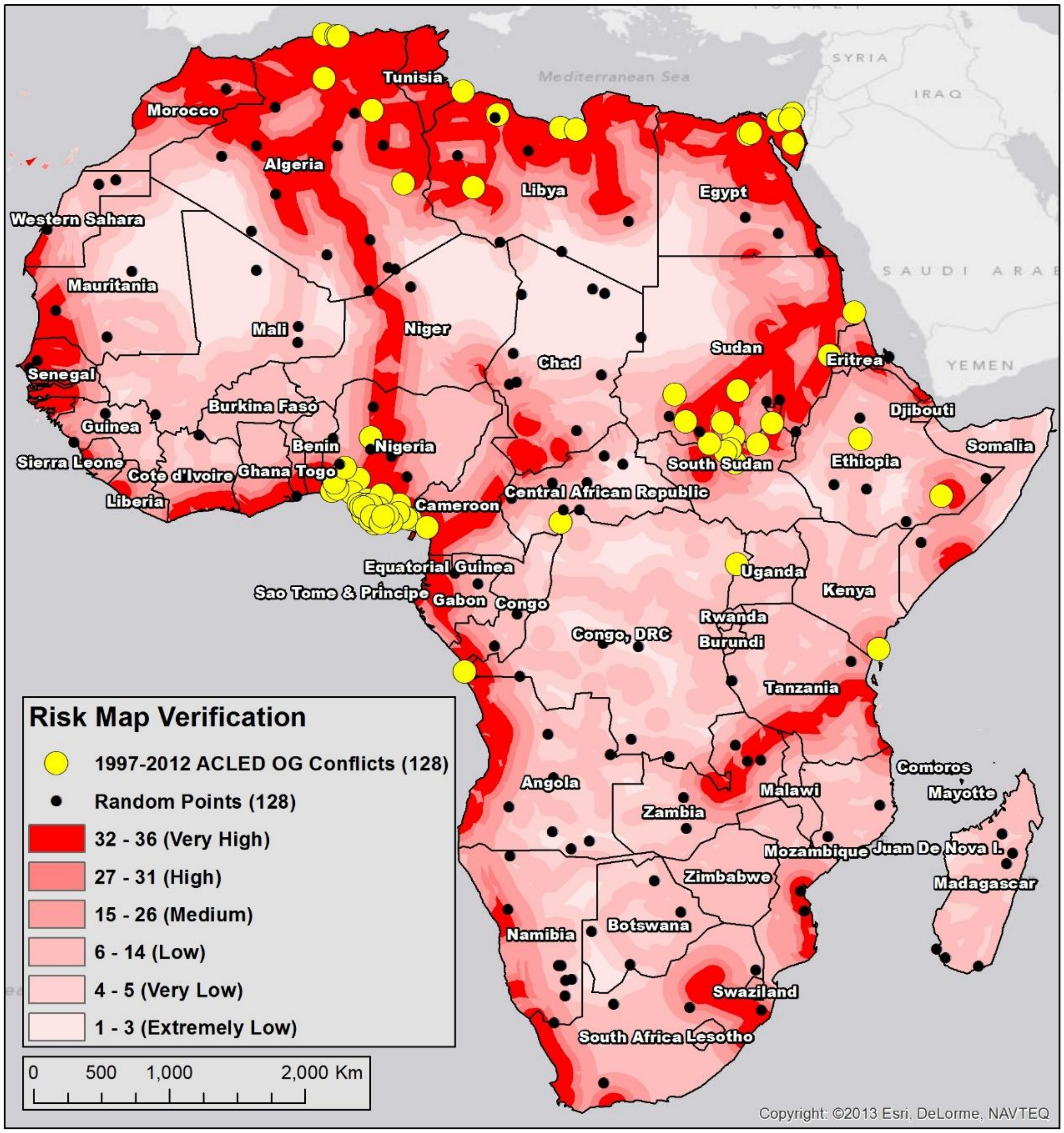
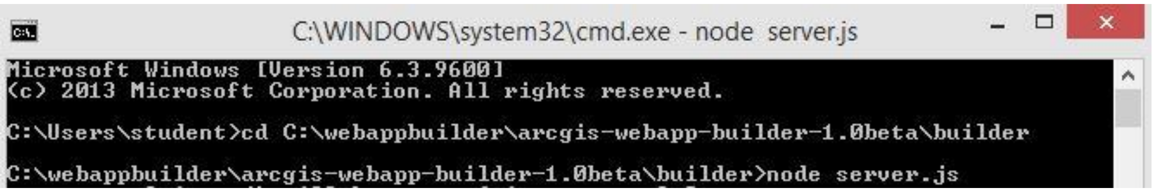


Figure 5-16: Random points and historical oil & gas conflict information

5.3 Web Mapping Application

An interface was required for the client to be able to view the spatial data that were acquired and created. Using a combination of an organizational ArcGIS Online (AGOL) account, University of Redlands (UR) publicly accessible webservers, and ArcGIS Web AppBuilder (WAB), a customizable interface was designed to meet the needs of the client. This system was published and handed off to the client on June 15, 2014.

The first step was to acquire the skills necessary to operate AGOL and WAB. These were acquired in early 2014 during instructor-led trainings by Esri staff. Once this knowledge was acquired, the beta version of WAB was downloaded and installed on a local machine from the Esri Beta Community website. The next step was to download the software node.js. This program is a platform built on Google Chrome's runtime for building applications. Once node.js was installed to the same directory as the WAB and run using the command line prompt (using the command node server.js) in Windows 8 (Figure 5-17), authoring of digital map content was able to take place.



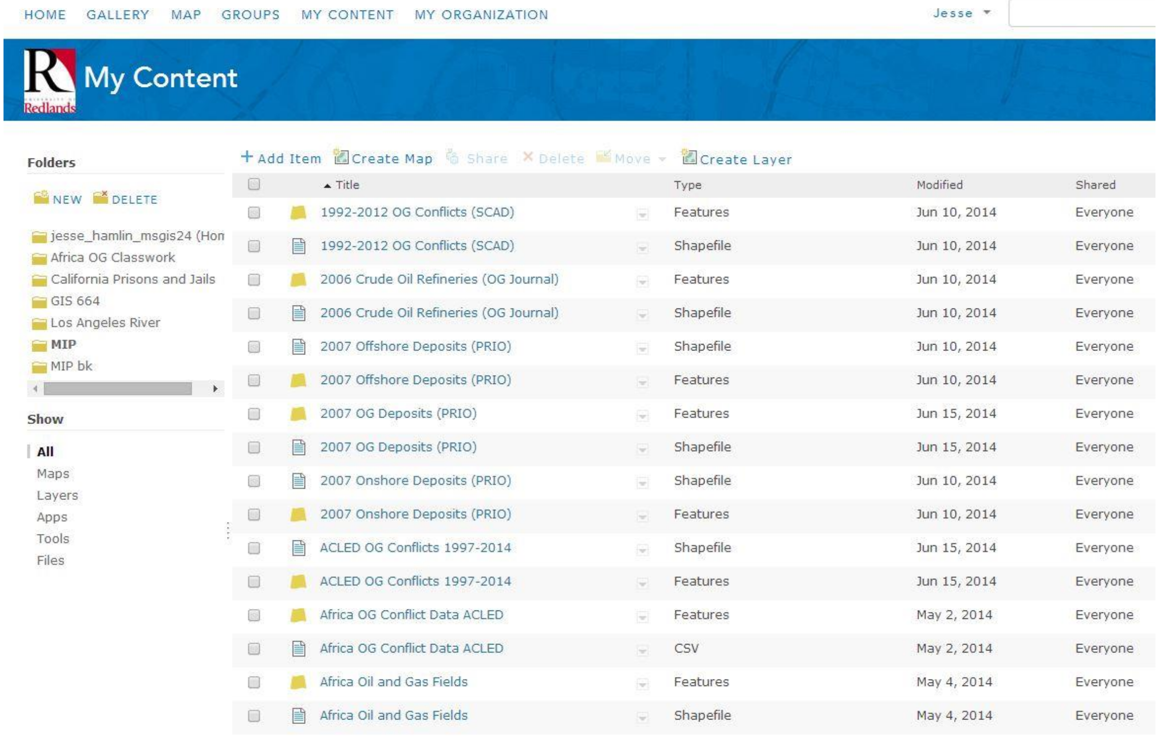
```
Microsoft Windows [Version 6.3.9600]
(c) 2013 Microsoft Corporation. All rights reserved.

C:\Users\student>cd C:\webappbuilder\arcgis-webapp-builder-1.0beta\builder

C:\webappbuilder\arcgis-webapp-builder-1.0beta\builder>node server.js
```

Figure 5-17: Initializing node.js using the Windows command prompt

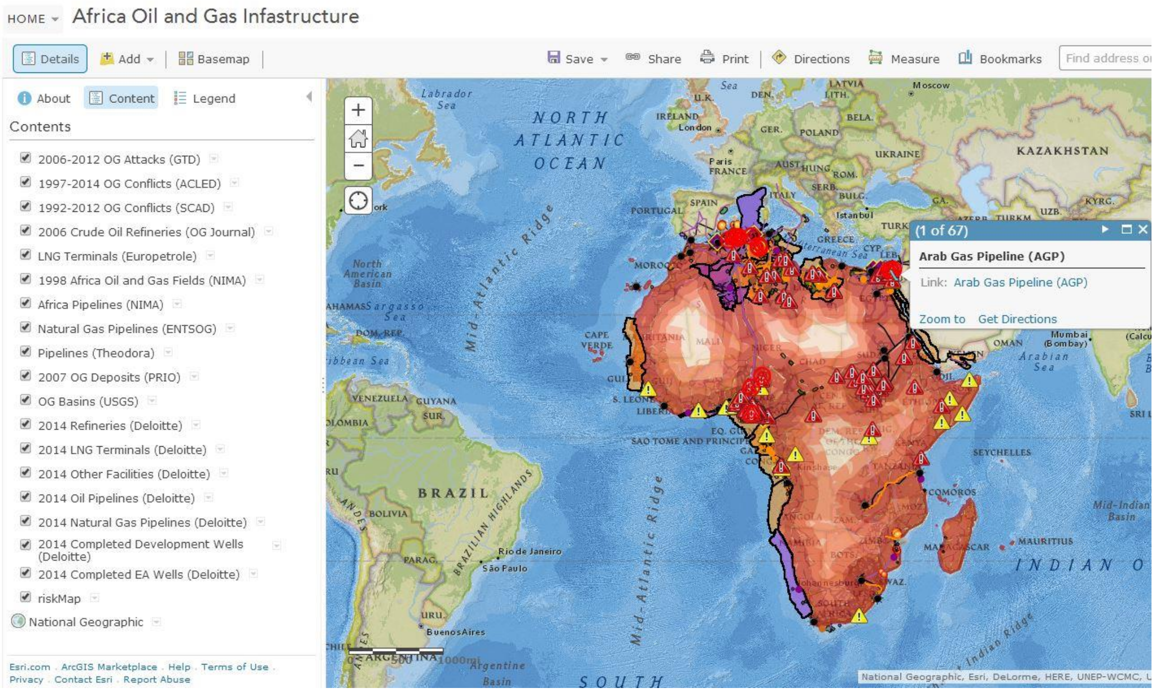
In order to create a custom web application using WAB, map content first needed to be published using AGOL. An organizational AGOL account was required in order to publish feature services for each required layer. All relevant layers were exported out of ArcGIS 10.2 as shapefiles, zipped up, re-projected to WGS 1984 Web Mercator Auxilliary Sphere, and then published as feature services using the University of Redlands organizational account (Figure 5-18).



Title	Type	Modified	Shared
1992-2012 OG Conflicts (SCAD)	Features	Jun 10, 2014	Everyone
1992-2012 OG Conflicts (SCAD)	Shapefile	Jun 10, 2014	Everyone
2006 Crude Oil Refineries (OG Journal)	Features	Jun 10, 2014	Everyone
2006 Crude Oil Refineries (OG Journal)	Shapefile	Jun 10, 2014	Everyone
2007 Offshore Deposits (PRIO)	Shapefile	Jun 10, 2014	Everyone
2007 Offshore Deposits (PRIO)	Features	Jun 10, 2014	Everyone
2007 OG Deposits (PRIO)	Features	Jun 15, 2014	Everyone
2007 OG Deposits (PRIO)	Shapefile	Jun 15, 2014	Everyone
2007 Onshore Deposits (PRIO)	Shapefile	Jun 10, 2014	Everyone
2007 Onshore Deposits (PRIO)	Features	Jun 10, 2014	Everyone
ACLED OG Conflicts 1997-2014	Shapefile	Jun 15, 2014	Everyone
ACLED OG Conflicts 1997-2014	Features	Jun 15, 2014	Everyone
Africa OG Conflict Data ACLED	Features	May 2, 2014	Everyone
Africa OG Conflict Data ACLED	CSV	May 2, 2014	Everyone
Africa Oil and Gas Fields	Features	May 4, 2014	Everyone
Africa Oil and Gas Fields	Shapefile	May 4, 2014	Everyone

Figure 5-18: University of Redlands AGOL organizational account

A web map was created to store each layer, then each layer was themed, scaled, and configured for pop-ups (Figure 5-19).



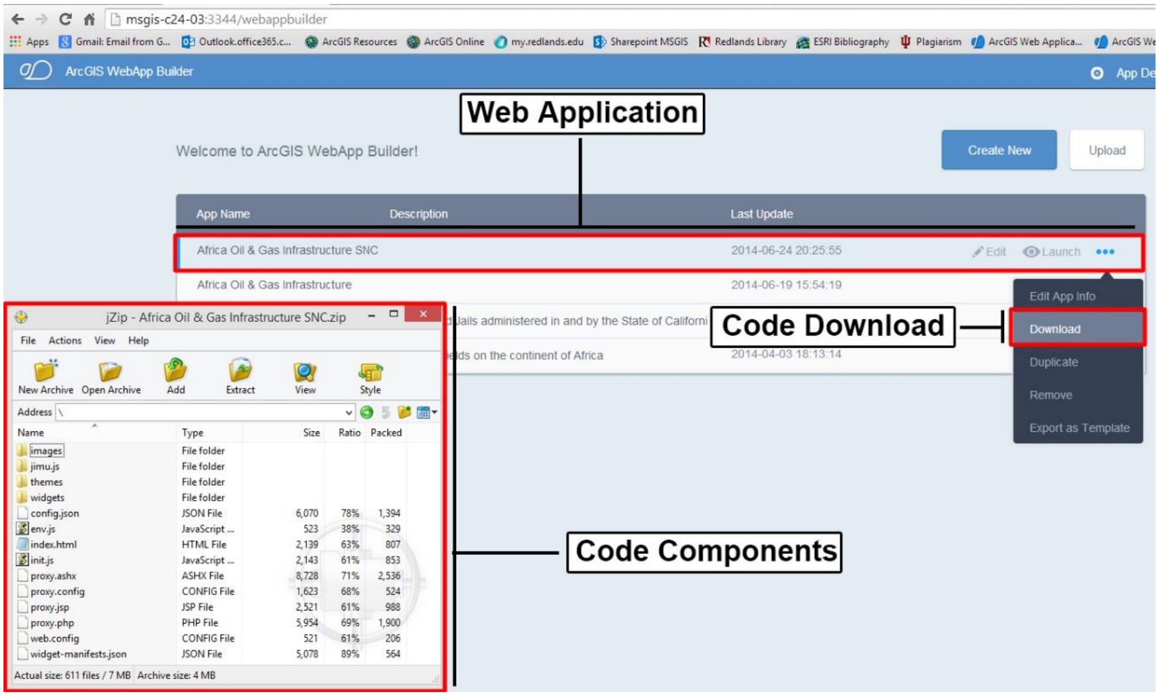
☑ 2006-2012 OG Attacks (GTD)
☑ 1997-2014 OG Conflicts (ACLED)
☑ 1992-2012 OG Conflicts (SCAD)
☑ 2006 Crude Oil Refineries (OG Journal)
☑ LNG Terminals (Europetrole)
☑ 1998 Africa Oil and Gas Fields (NIMA)
☑ Africa Pipelines (NIMA)
☑ Natural Gas Pipelines (ENTSOG)
☑ Pipelines (Theodora)
☑ 2007 OG Deposits (PRIO)
☑ OG Basins (USGS)
☑ 2014 Refineries (Deloitte)
☑ 2014 LNG Terminals (Deloitte)
☑ 2014 Other Facilities (Deloitte)
☑ 2014 Oil Pipelines (Deloitte)
☑ 2014 Natural Gas Pipelines (Deloitte)
☑ 2014 Completed Development Wells (Deloitte)
☑ 2014 Completed EA Wells (Deloitte)
☑ riskMap
National Geographic

(1 of 67)
Arab Gas Pipeline (AGP)
Link: Arab Gas Pipeline (AGP)
Zoom to Get Directions

Figure 5-19: AGOL web map containing all relevant OG data for the project

The next steps performed were the creation and authoring of the web application using the WAB. This required running the WAB on a local machine. A new application — Africa Oil & Gas Infrastructure Security (SNC) — was then created. Within the application author, an interface customized to meet the needs of the client was constructed. This included selecting a sufficient theme, creating custom widgets such as bookmarks, measuring tools, a basemap selection tool from AGOL, and others. A title and client logo were also uploaded to match the application theme selected. WAB mapping content was pulled from a single file format, the AGOL web map. The Africa Oil & Gas Infrastructure web map created in AGOL was imported. The web mapping application was now complete.

The next step was to host this web application publicly using University of Redlands public webservers. This involved the creation of a public webserver by the Information Technology Services (ITS) group at the University of Redlands MS GIS program. Once this webserver was created, the code (.JSON, JavaScript, and HTML files) from the WAB were exported from the application and placed on the public web server (Figure 5-20).



Name	Type	Size	Ratio	Packed
images	File folder			
jimu.js	File folder			
themes	File folder			
widgets	File folder			
config.json	JSON File	6,070	78%	1,394
env.js	JavaScript ...	523	38%	329
index.html	HTML File	2,139	63%	807
init.js	JavaScript ...	2,143	61%	853
proxy.ashx	ASHX File	8,728	71%	2,536
proxy.config	CONFIG File	1,623	68%	524
proxy.jsp	JSP File	2,521	61%	988
proxy.php	PHP File	5,954	69%	1,900
web.config	CONFIG File	521	61%	206
widget-manifests.json	JSON File	5,078	89%	564

Actual size: 611 files / 7 MB Archive size: 4 MB

Figure 5-20: Web application code export using ArcGIS Web AppBuilder Beta

Once the code was moved to the public webserver, the folder where the code was placed needed to be registered with Internet Information Services (IIS) in order for WAB to access the code from the server. This was completed by University of Redlands IT staff. The web application was now available for access outside of the University of Redlands campus IT network.

The next phase consisted of testing to make sure the application was fully accessible and all the features worked properly. The client confirmed they were able to access the application and all components were working on May 21, 2014. In an attempt to perform additional testing, the contractor confirmed that all widgets were working both in and outside the UR network. The next step was to test the application on mobile devices. Three separate devices were chosen: Apple iPad 3, the Samsung Galaxy S4, and the Apple iPhone 4s. All three applications were able to access the web application successfully. Performance will be discussed in Chapter 6.

5.4 Summary

After the data collection, three primary phases of implementation were completed. The first was the gathering of information regarding spatial analysis of risk. Once a theoretical model was chosen from established literature, a spatial analysis risk assessment for OG infrastructure security in Africa was performed. The second component of implementation was the verification of the existing risk model using independent OG conflict information. The last component of implementation was the creation and hosting of the web mapping application for the client. Chapter 6 will discuss the results of the analysis performed above, as well as describe the web mapping application in more detail.

Chapter 6 – Results and Analysis

Section 6.1 discusses the results of the OG infrastructure risk analysis that was performed at the Africa continent level. It also discusses accuracy verification of the analysis that was performed by using a quantitative measure: percent correctly classified. A detailed analysis of OG infrastructure risk for the countries of Algeria and Mozambique is discussed in Section 6.2. Section 6.3 examines the web mapping application that was constructed for the client.

6.1 Results and Verification

6.1.1 Results

One of the deliverables for the client was an analysis of OG infrastructure attack and theft risk. This analysis was conducted with the intention to predict the risk of intentional attacks. Natural accidents (e.g., earthquakes at refineries, oil platform lightning strikes) and technological accidents (e.g., BP deep water horizon oil spill in Galveston, Texas, Exxon Valdez oil spill in Alaska) were not predicted using this model. Examples of intentional attacks that can be predicted using this model include refinery and pipeline attacks, oil tanker hijackings, and natural gas facility hostage crises. Burgherr (2010) provides some cases below which were adapted by the author for this report (Figure 6-1).

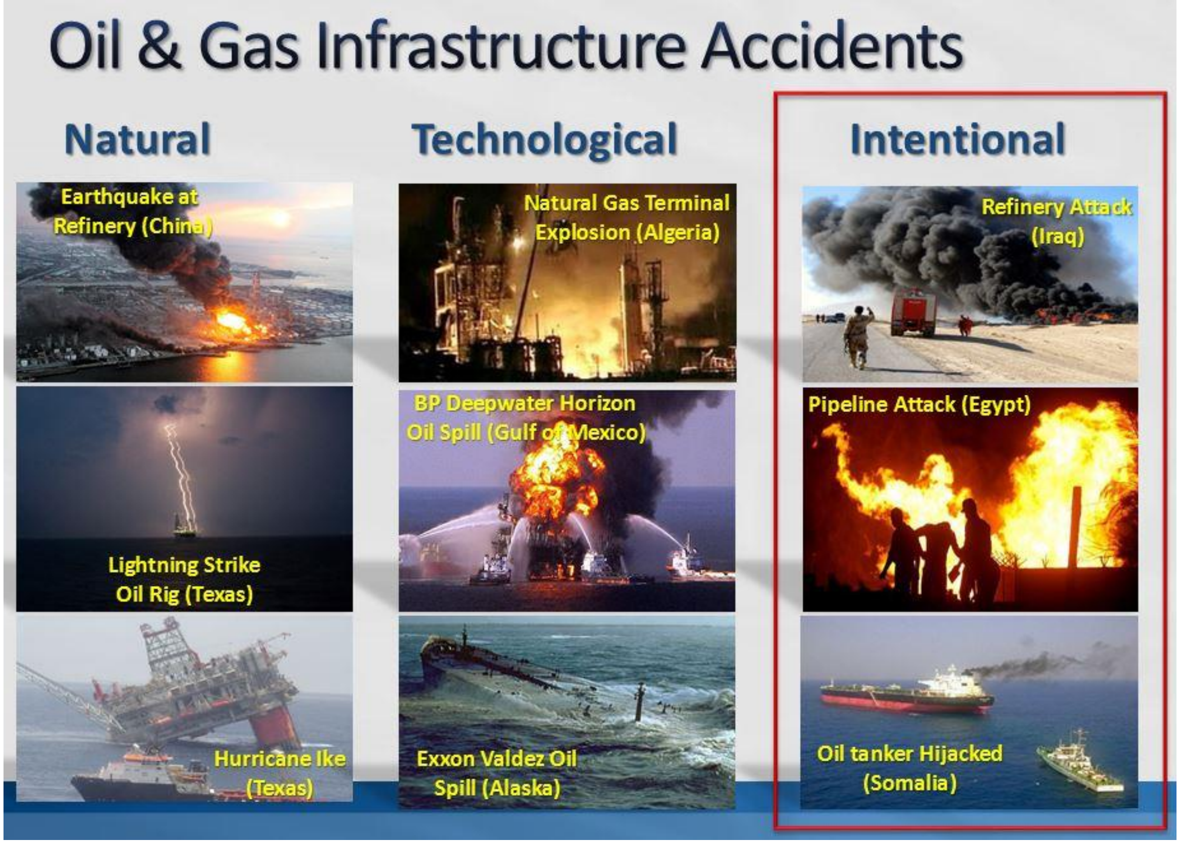


Figure 6-1: Oil and gas infrastructure attacks

In order to produce results identifying areas of low and high risk, a formula was used. Hazard and vulnerability, which have been discussed at length in previous chapters, were multiplied together to generate an output map for risk with values ranging from 1 to 25 (Figure 6-2).

Figure 6-2: Risk map generation

The first result was the creation of the hazard map. This incorporated variables from the physical environment, such as proximity to geological basins or proximity to existing OG deposits, and built environment (e.g., proximity to pipelines) in order to produce the following result (Figure 6-3). This map displayed several trends. The first was that proximity to geological basins, deposit areas, and OG infrastructure were assigned high hazard. Areas that were not in close proximity to these features were assigned low hazard. Countries with large amounts of existing OG infrastructure and existing geological oil and gas basins, such as Algeria, Libya, Nigeria, and Egypt, had large amounts of high-hazard areas. Countries in the interior with no access to geological oil and gas basins, with little OG infrastructure such as the Congo, Botswana, and Mali, had large areas of low hazard areas (Figure 6-3). This information was consistent with the values expected prior to GIS analysis.

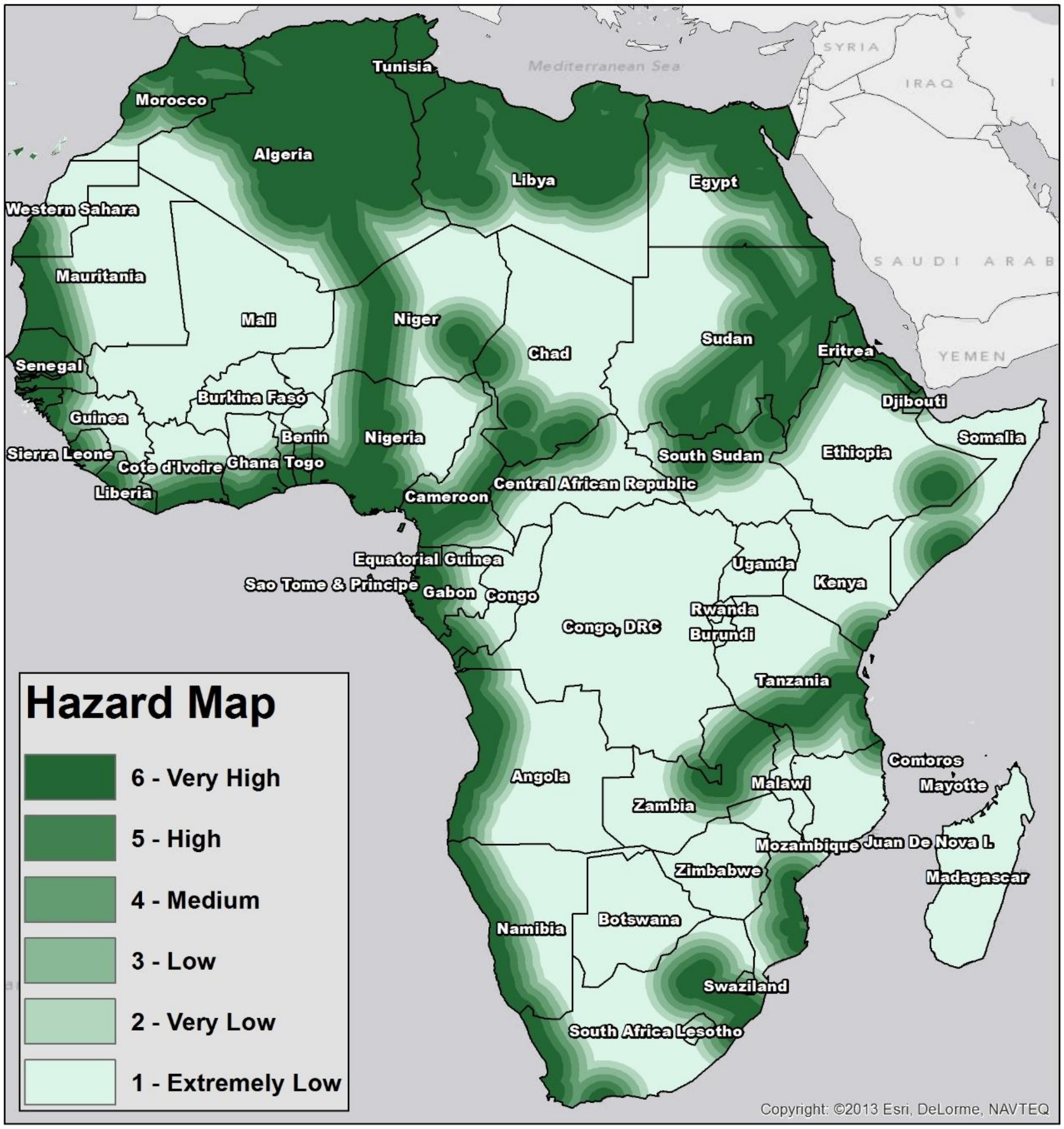
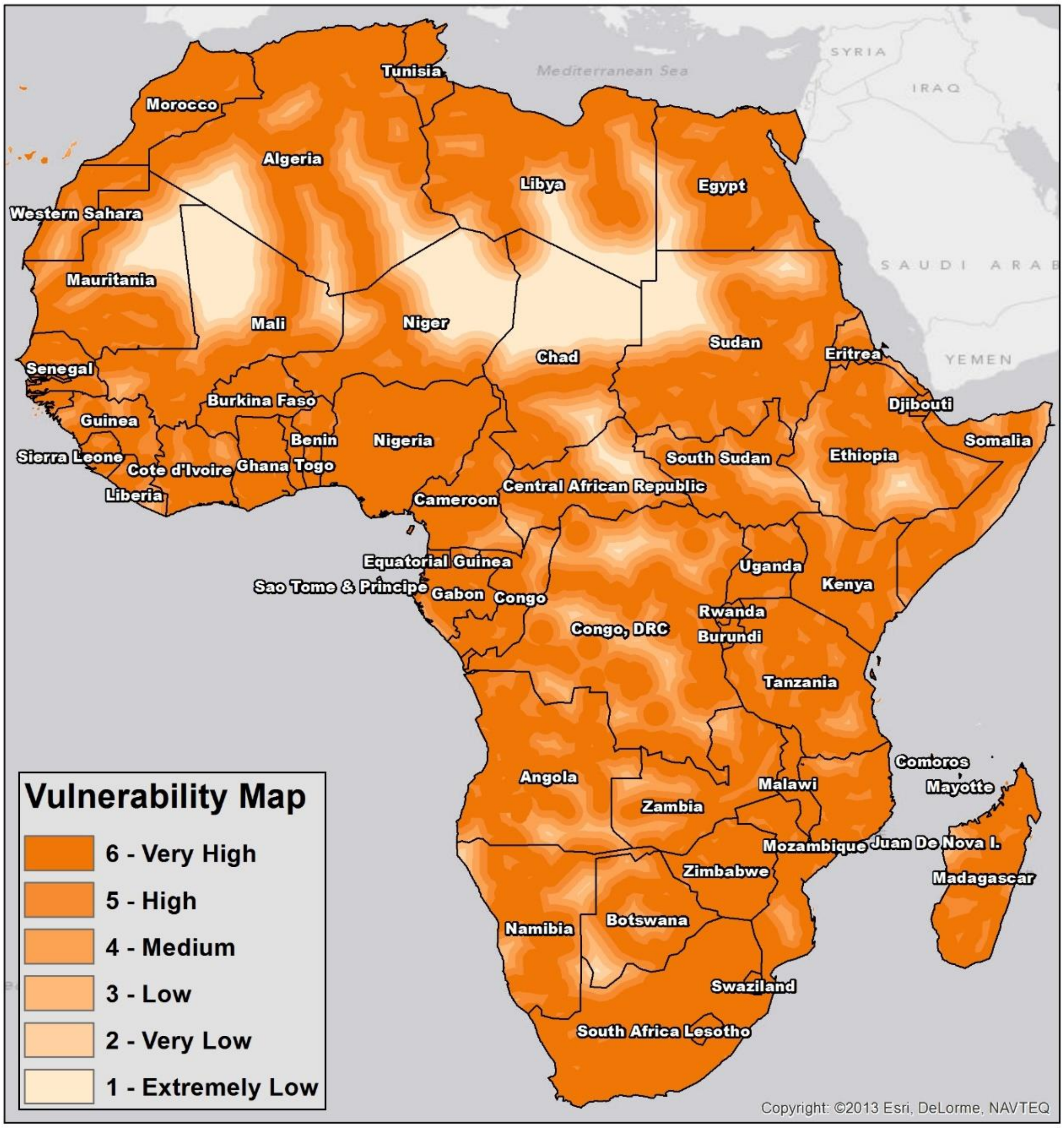


Figure 6-3: Hazard map

The second analysis result was the vulnerability map. This was generated from variables pertaining mostly to human-related elements, such as proximity to urban areas and major highways, presence of terror groups and social conflicts in the region, and adjacency. For this particular result, countries with high levels of infrastructure and population most often corresponded positively with higher vulnerability. Examples of countries with high vulnerability include South Africa, Nigeria, Algeria, Libya, and Egypt. Relatively uninhabited areas, such as those countries located within the Sahara Desert − Chad, Niger, Mali, and Mauritania − contained low levels of vulnerability (Figure 6-4).



Copyright: ©2013 Esri, DeLorme, NAVTEQ

Figure 6-4: Vulnerability map

After both hazard and vulnerability were calculated, an intermediary risk map was produced. By using the multiplication method (See Figure 6-2) performed using the raster calculator, a raster was produced for overall OG infrastructure security risk on a scale of 1-36 using the natural breaks classification scheme (Figure 6-5).

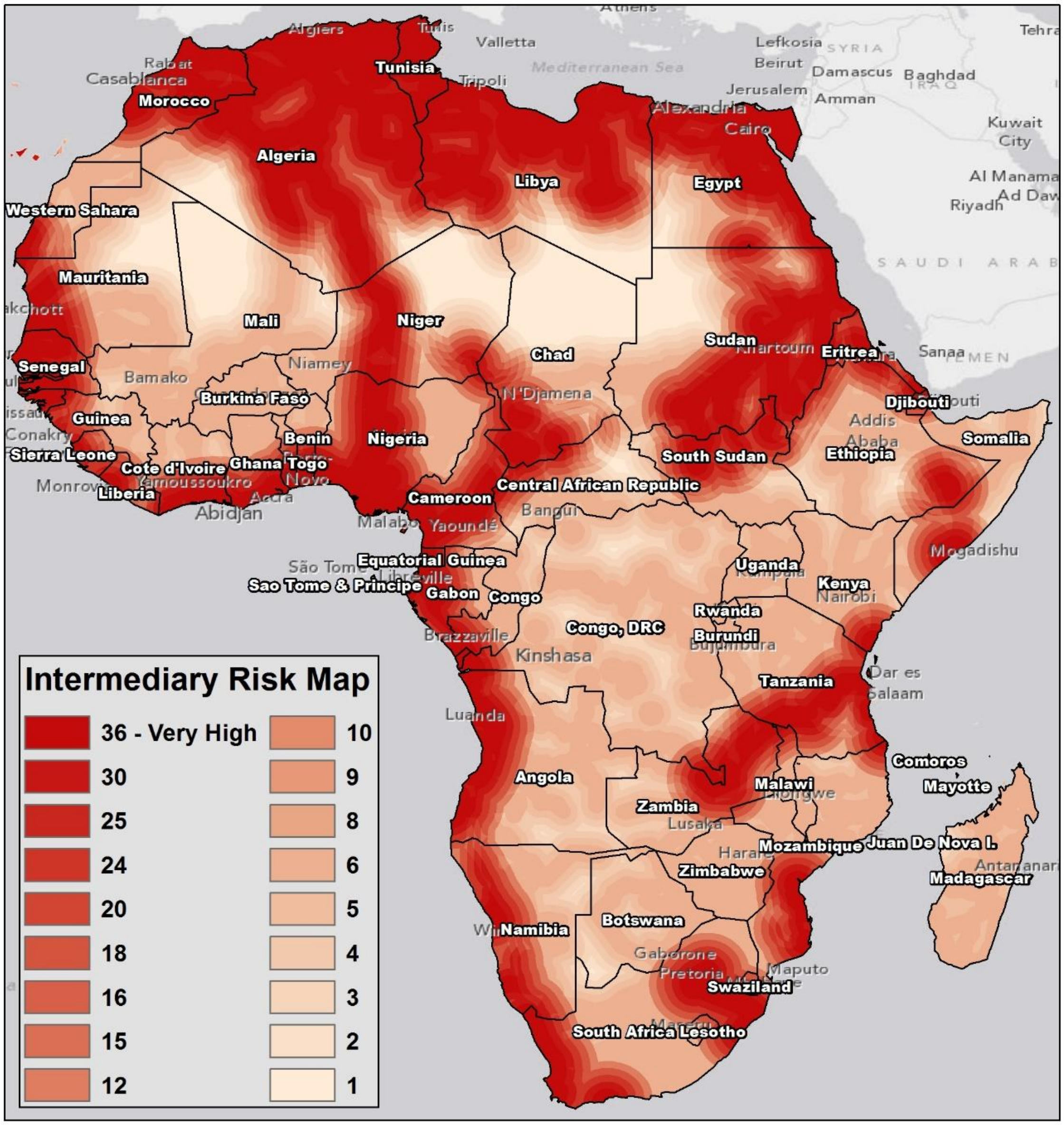


Figure 6-5: Intermediary risk map

A manual classification scheme was applied to the data, and the data were manually grouped into classes from 1-6. The classification helped emphasize high values to help identify high risk areas more efficiently (Figure 6-6). Classification breaks were set manually in order to emphasize class 32-36 (Very High) and also be able to see variations in the remaining five classes.

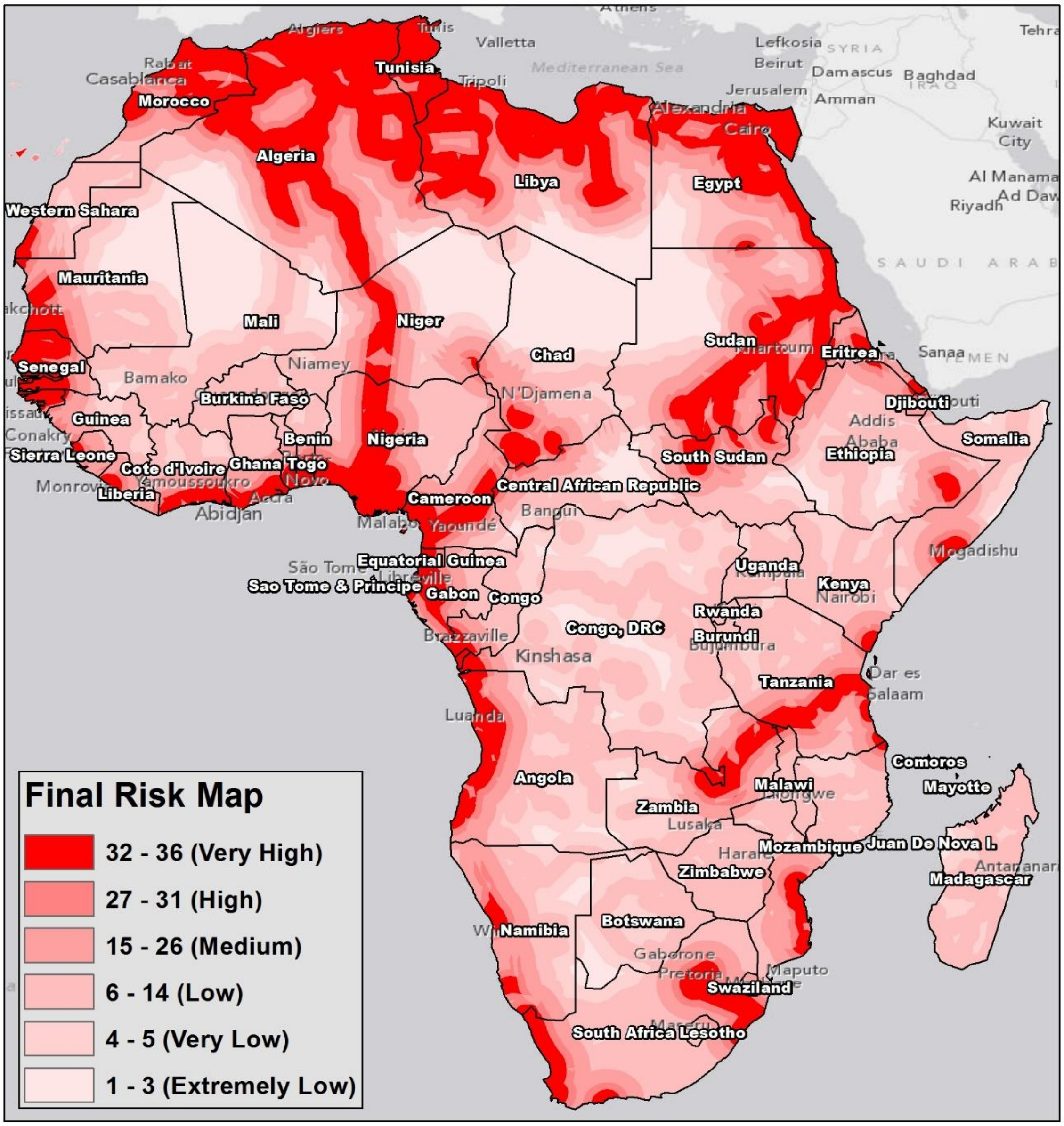


Figure 6-6: Final Risk map

There are several interesting observations one can understand from the result. The first is that the countries of Algeria, Libya, Egypt, Sudan, and Nigeria are the countries which have the most cumulative risk. There are two ways to interpret this. The first is through a visual inspection (Figure 6-7).

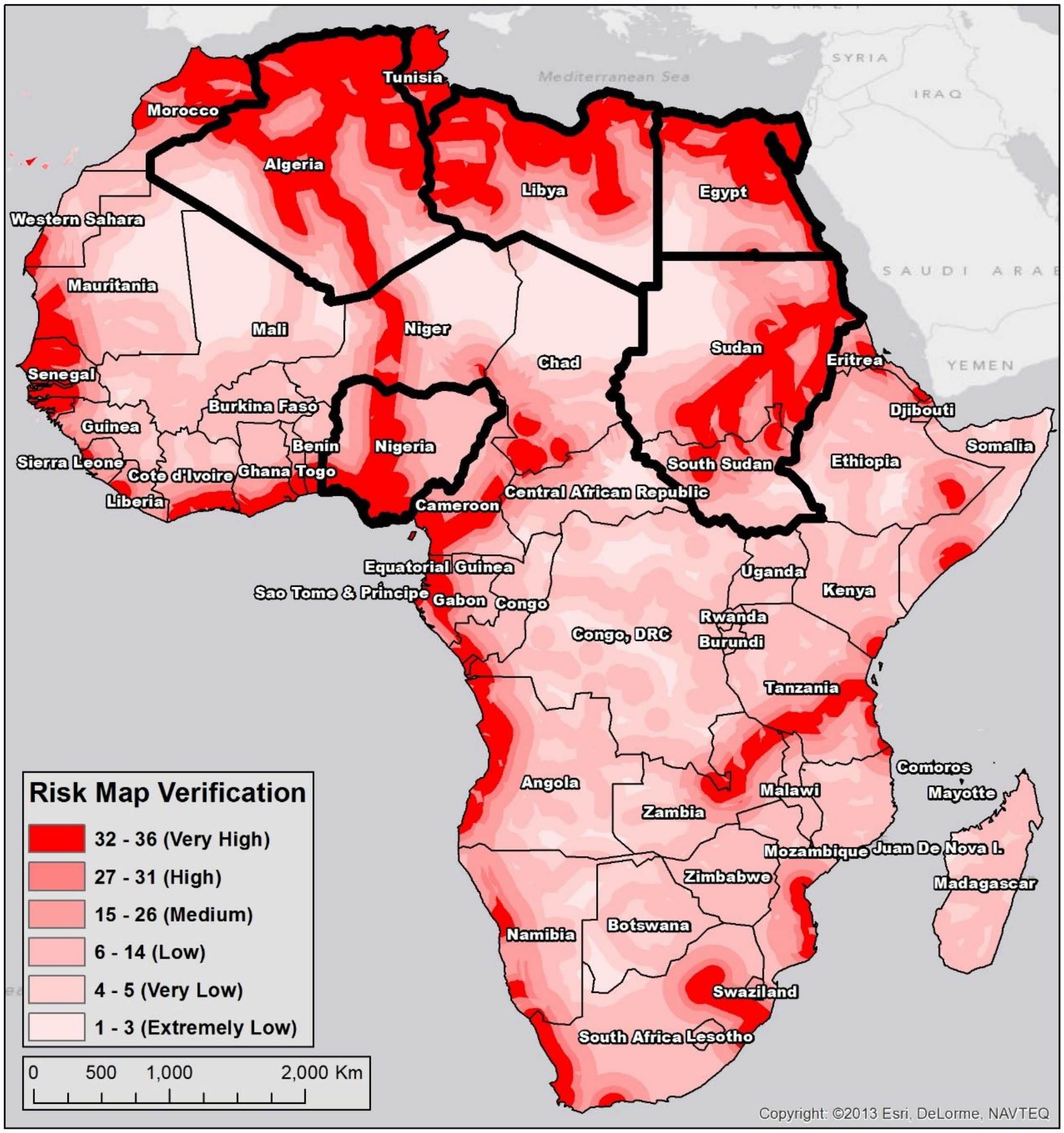
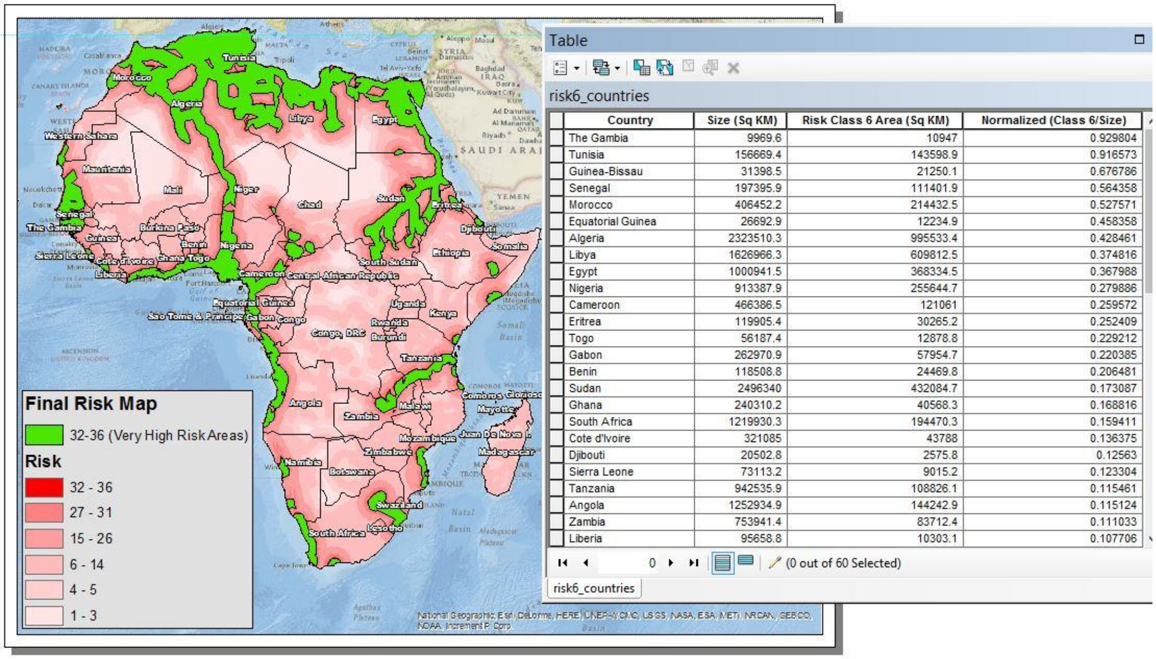


Figure 6-7: High risk countries

The second is to quantify the amount of high risk areas per country, in other words the amount of area for the very high risk class from 32-36. This was performed using the Tabulate Areas tool. After the area was calculated, this number was normalized based on country size to produce the following result (Figure 6-8). The top 5 countries for risk are The Gambia, Tunisia, Guinea Sassau, Senegal, and Morocco. There is an issues with this method because smaller countries may be more vulnerable to risk spillover from other large countries when analysis is performed at a low scale. The client is interested in identifying large countries for overall risk.



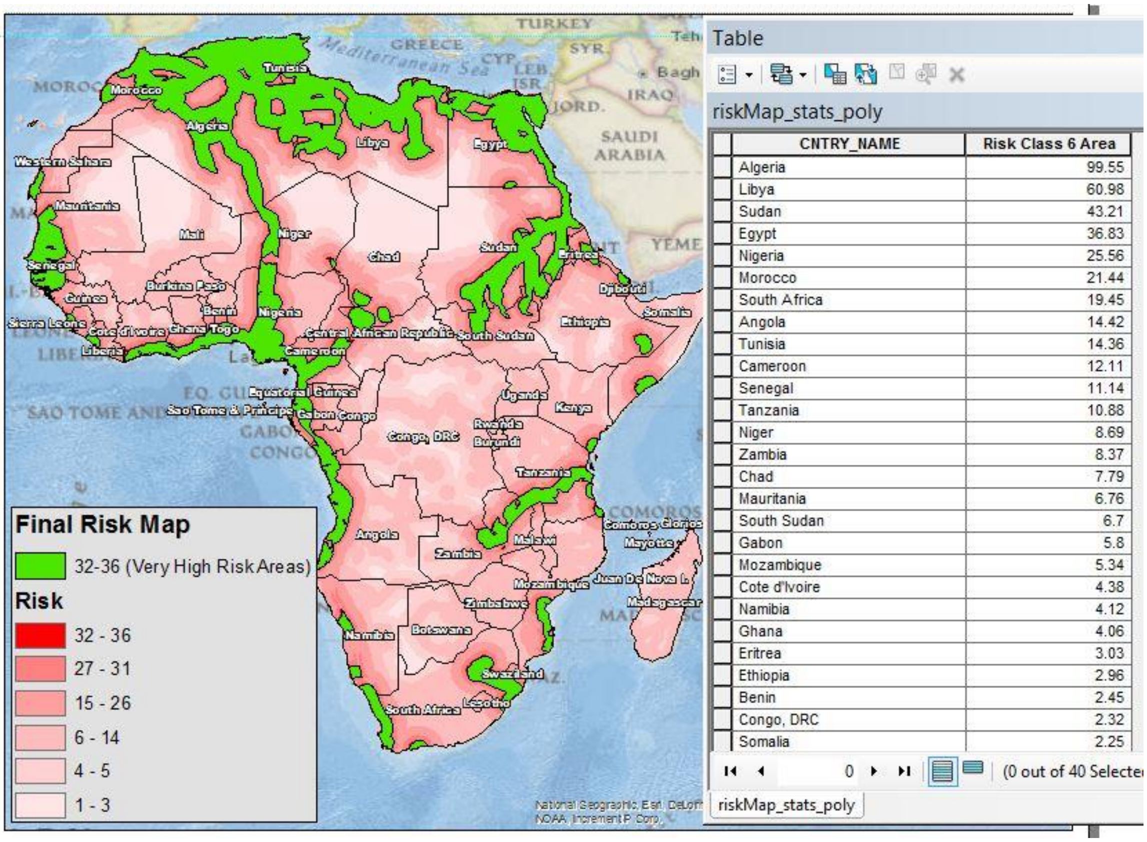
Country	Size (Sq KM)	Risk Class 6 Area (Sq KM)	Normalized (Class 6/Size)
The Gambia	9969.6	10947	0.929804
Tunisia	156669.4	143598.9	0.916573
Guinea-Bissau	31398.5	21250.1	0.676786
Senegal	197395.9	111401.9	0.564358
Morocco	406452.2	214432.5	0.527571
Equatorial Guinea	26692.9	12234.9	0.458358
Algeria	2323510.3	995533.4	0.428461
Libya	1626966.3	609812.5	0.374816
Egypt	1000941.5	368334.5	0.367988
Nigeria	913387.9	255644.7	0.279886
Cameroon	466386.5	121061	0.259572
Eritrea	119905.4	30265.2	0.252409
Togo	56187.4	12878.8	0.229212
Gabon	262970.9	57954.7	0.220385
Benin	118508.8	24469.8	0.206481
Sudan	2496340	432084.7	0.173087
Ghana	240310.2	40568.3	0.168816
South Africa	1219930.3	194470.3	0.159411
Cote d'Ivoire	321085	43788	0.136375
Djibouti	20502.8	2575.8	0.12563
Sierra Leone	73113.2	9015.2	0.123304
Tanzania	942535.9	108826.1	0.115461
Angola	1252934.9	144242.9	0.115124
Zambia	753941.4	83712.4	0.111033
Liberia	95658.8	10303.1	0.107706

(0 out of 60 Selected)

risk6_countries

Figure 6-8: Top countries for risk quantified using the Tabulate Areas tool

As a solution to this problem, the total amount of risk per country was calculated without normalization (in hundreds of square kilometers, e.g. 60.98 = 600,980 square kilometers). The resulting table shows that the top 5 countries for risk are Algeria, Libya, Sudan, Egypt, and Nigeria (Figure 6-9) in terms of total area. This information matches the results from the visual inspection.



CNTRY_NAME	Risk Class 6 Area
Algeria	99.55
Libya	60.98
Sudan	43.21
Egypt	36.83
Nigeria	25.56
Morocco	21.44
South Africa	19.45
Angola	14.42
Tunisia	14.36
Cameroon	12.11
Senegal	11.14
Tanzania	10.88
Niger	8.69
Zambia	8.37
Chad	7.79
Mauritania	6.76
South Sudan	6.7
Gabon	5.8
Mozambique	5.34
Cote d'Ivoire	4.38
Namibia	4.12
Ghana	4.06
Eritrea	3.03
Ethiopia	2.96
Benin	2.45
Congo, DRC	2.32
Somalia	2.25

Figure 6-9: Top countries for risk quantified using the Tabulate Areas tool

The second observation is that countries with both high levels of hazard and vulnerability (e.g. Algeria, Libya, Egypt, Sudan, Nigeria) have the highest levels of overall risk. This is because the model used a multiplication method. For example, the country of South Africa has some of the highest levels of vulnerability on the continent (see Figure 6-4). However, the country has an average to low level of hazard because the country has relatively little OG infrastructure (see Figure 6-3). As such, the overall level of risk is quite low in comparison with countries that have high levels of both risk and vulnerability (e.g., Algeria, Libya, Nigeria). It is worth noting that just because a country does not have OG infrastructure, it does not mean that it will certainly have low levels of risk. For example, Somalia currently has low levels of OG infrastructure. One of the reasons for this is that the existence of oil and gas reserves in Somalia have not been fully assessed, only estimated (Central Intelligence Agency, n.d.). Currently the risk model suggests that Somalia has moderate levels of risk, even though no infrastructure is present. This illustrates that the model is not completely dependent on the existence of OG infrastructure. If oil in Somalia is discovered and infrastructure is built, this risk level would most certainly go up. An estimate would be as much or possibly even more than the current high-risk countries of Algeria, Libya, Egypt, Nigeria, and Sudan. This is because Somalia has very high levels of social conflict (see Figure 5-10) and a high presence of terror groups in comparison with other countries.

6.1.2 Verification

To understand how accurate the risk model was, verification was necessary. This was conducted in two ways. The first was through a visual data inspection. A completely independent set of OG infrastructure attack point data were overlaid on the final risk model (Figure 6-10). The source of the data was the Armed Conflict Location and Event Database (ACLED) from 1997-2012. The points in yellow correspond with the top classes of the risk map shown in dark red. Many of the points are located within areas with high levels of risk, such as Algeria, Libya, Sudan, Egypt, and Nigeria (Figure 6-10). The second method was through quantifying the accuracy of the model. This was done using the percent correctly classified method, a technique commonly used in remote sensing classification assessment. In this technique the number of true locations that were classified correctly are divided by the total amount of true locations and multiplied by 100, yielding the percent of locations that were correctly classified. Using the Extract Values to Points tool in ArcMap 10.2, the pixel values from the risk raster were extracted to each individual point. The result showed that 94.5% of the points (shown in yellow) fall within the top two classes (32-36 very high and 27-31 high) of the raster. 89% of the values fall within the top class (32-36 very high). More details can be found below (Figure 6-10).

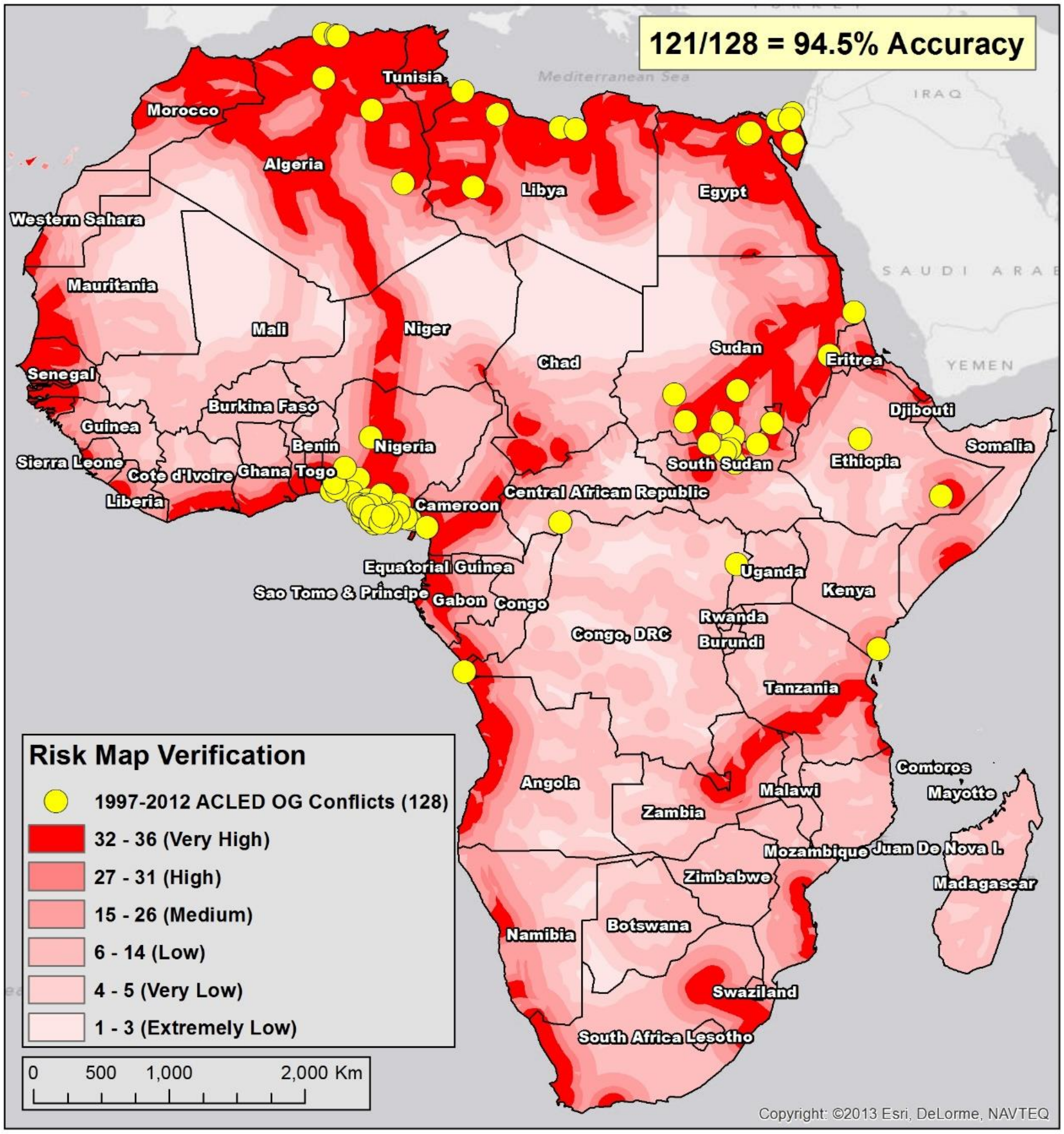


Figure 6-10: Verification using an independent point dataset

An additional method was employed to account for the factor known as complete spatial randomness (CSR). This assumes that among a given number of points, an unspecified number will occur in a specified area due to randomness. In order to test for this, 128 randomly sampled points were overlaid on the risk raster (Figure 6-11).

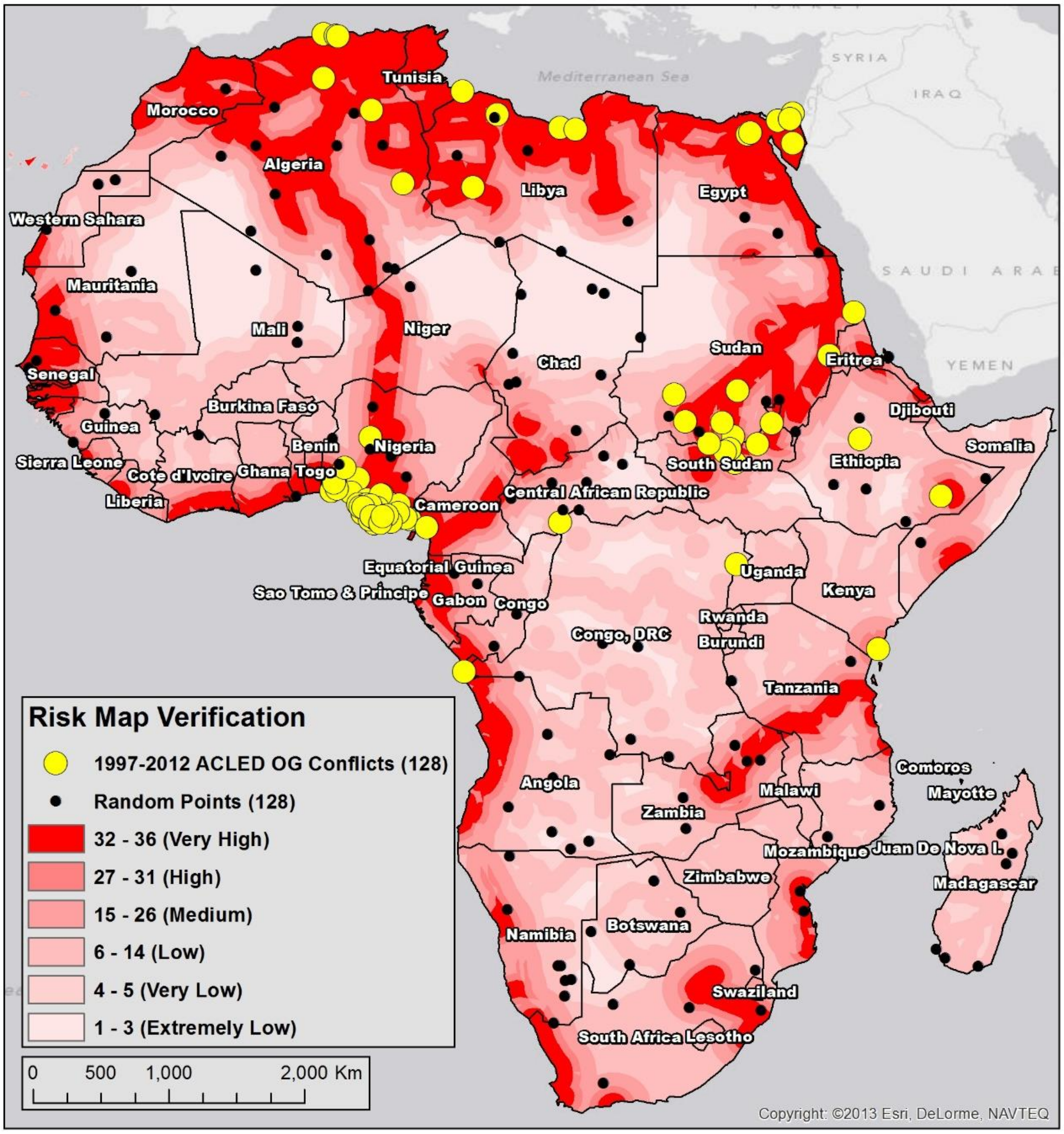


Figure 6-11: Random points and historical oil and gas conflict information

The values from the raster were then extracted to the 128 random points using the Extract Values to Points tool in ArcGIS 10.2. Thirty-seven points, or approximately 28.9% of the values fell within the top 2 classes for risk (5 – Very High and 4 – High) (Figure 6-12).

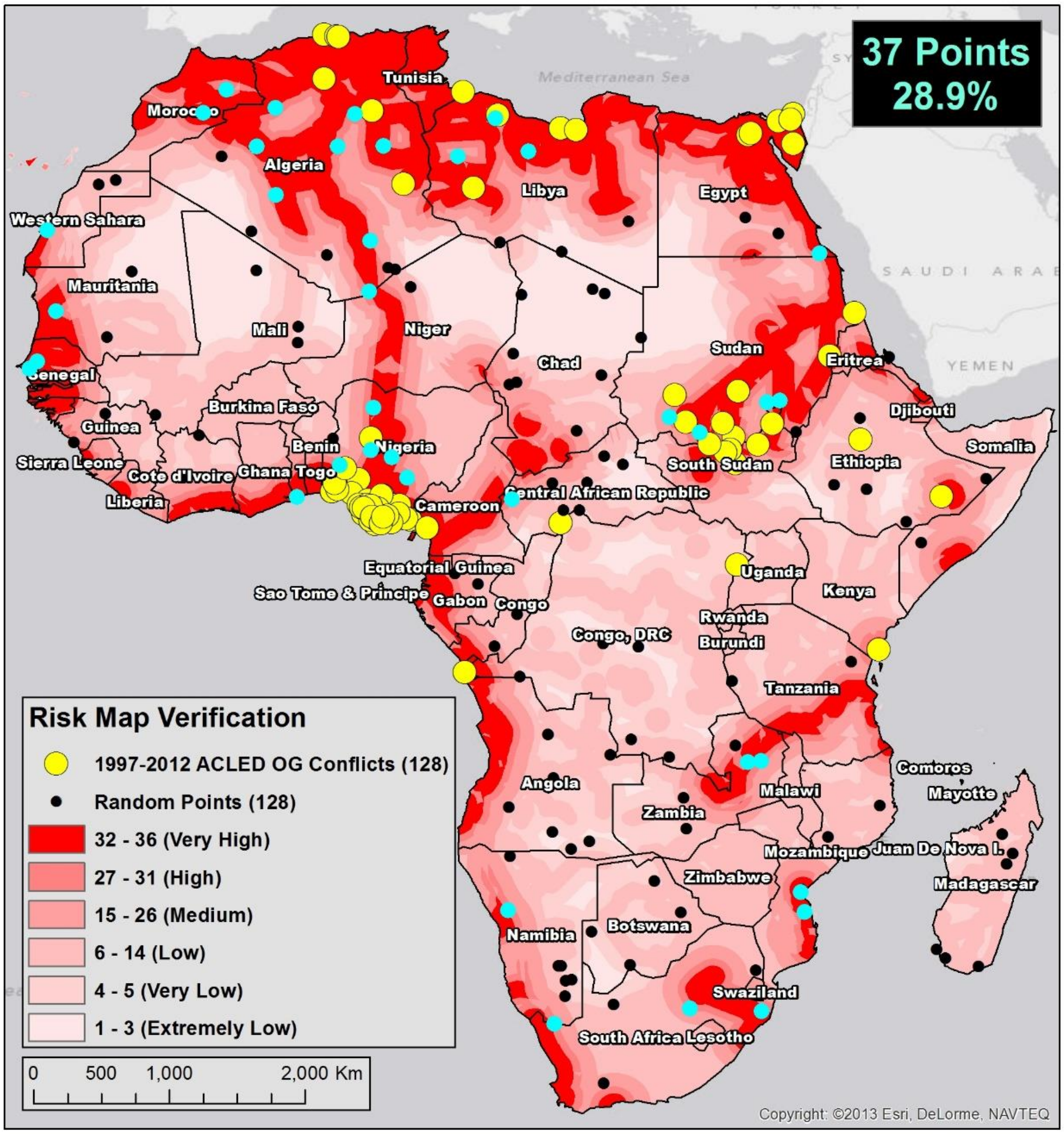


Figure 6-12: Points occurring in top 2 risk classes due to space randomness

Approximately 28.9% or 37 of the points occurred in the top 2 classes for risk due to CSR. By subtracting this number (37) from the original number of classified points (121), CSR was accounted for and the final model accuracy was determined to be 65.6% or 84 points correctly classified (Figure 6-13). This means the model is 65.6% accurate after accounting for spatial randomness.

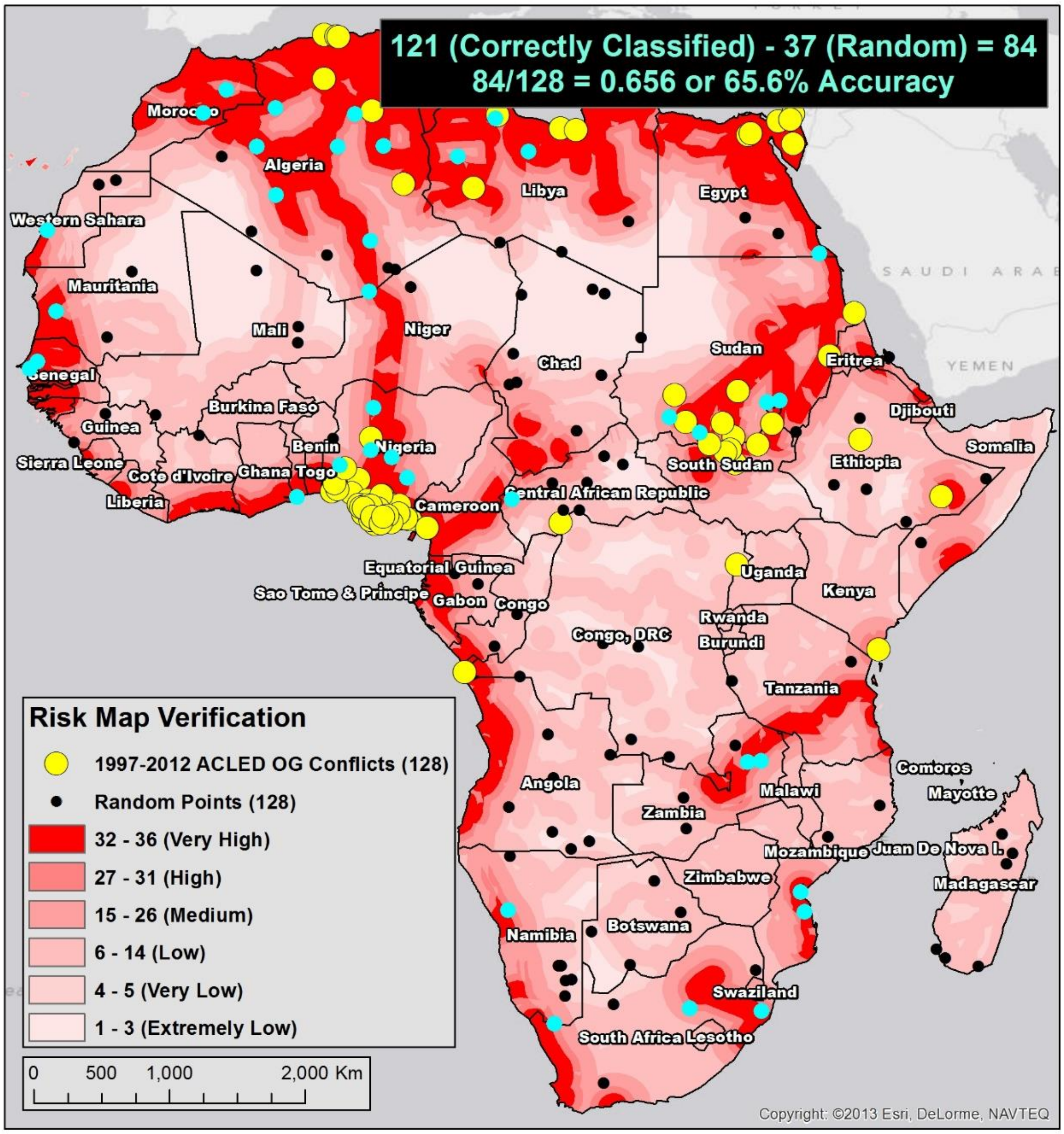


Figure 6-13: Model accuracy when accounting for CSR

6.2 Country Level Analysis

A final step in verifying the accuracy of the model was to run the analysis at a more detailed level. Detailed data were purchased from Deloitte Group for Northern Algeria and Southern Mozambique. These data were not only more detailed, but more current (the data was updated in May 2014). The data included exploration and appraisal wells (completed), development wells (completed), other facilities, refineries, LNG terminals, oil pipelines, and natural gas pipelines. Each of these datasets represents facilities and infrastructure that are actively running/performing. No abandoned infrastructure information was included. Maps of the datasets are shown below (Figure 6-14).

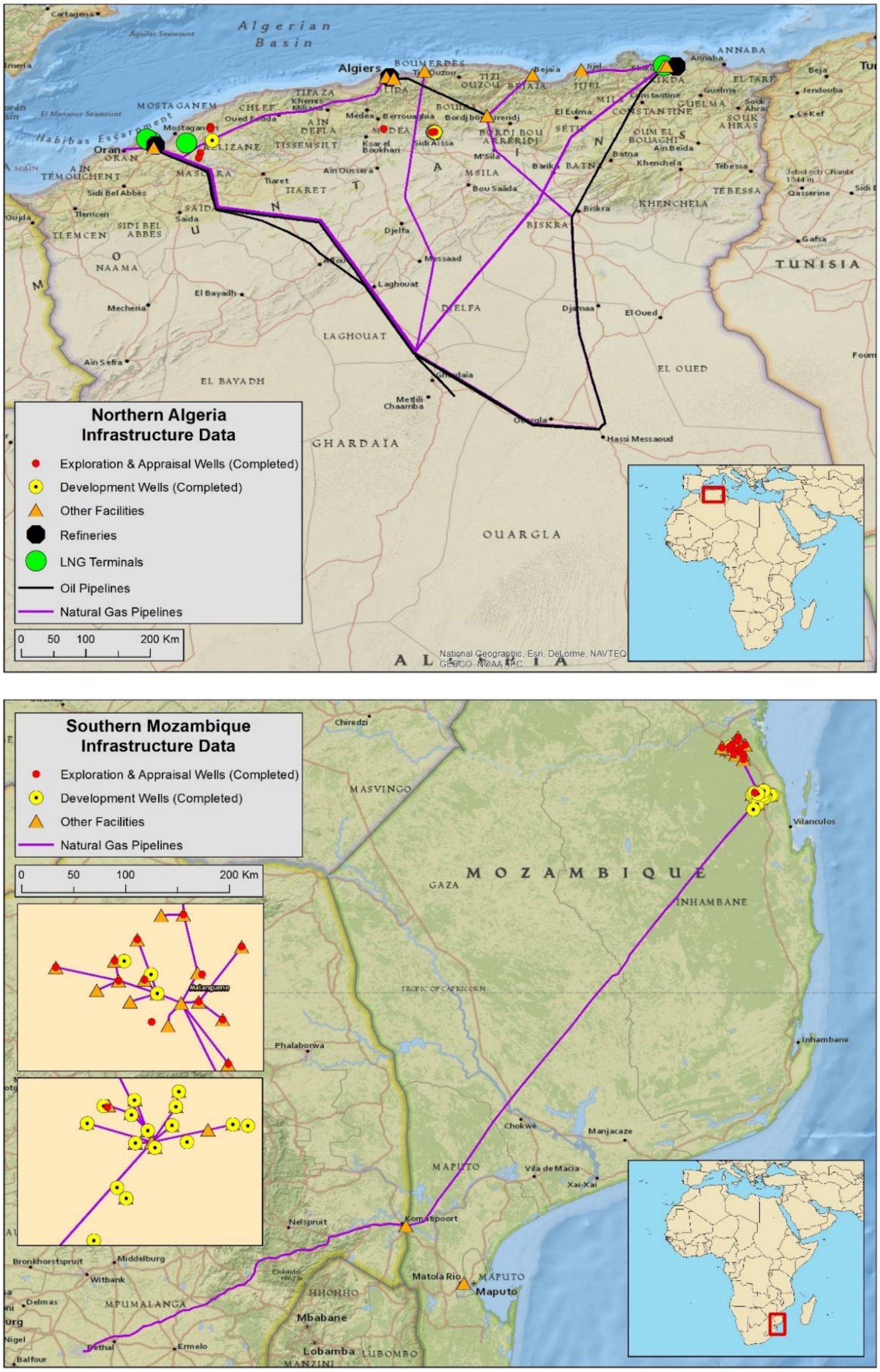


Figure 6-14: Detailed datasets for Northern Algeria and Southern Mozambique

The same risk analysis that was run at the continental level for Africa was run on the detailed infrastructure data for Algeria and Mozambique with the same buffer distances. The same manual classification scheme that was used for the continental risk maps was used for the detailed risk maps (Figure 6-15).

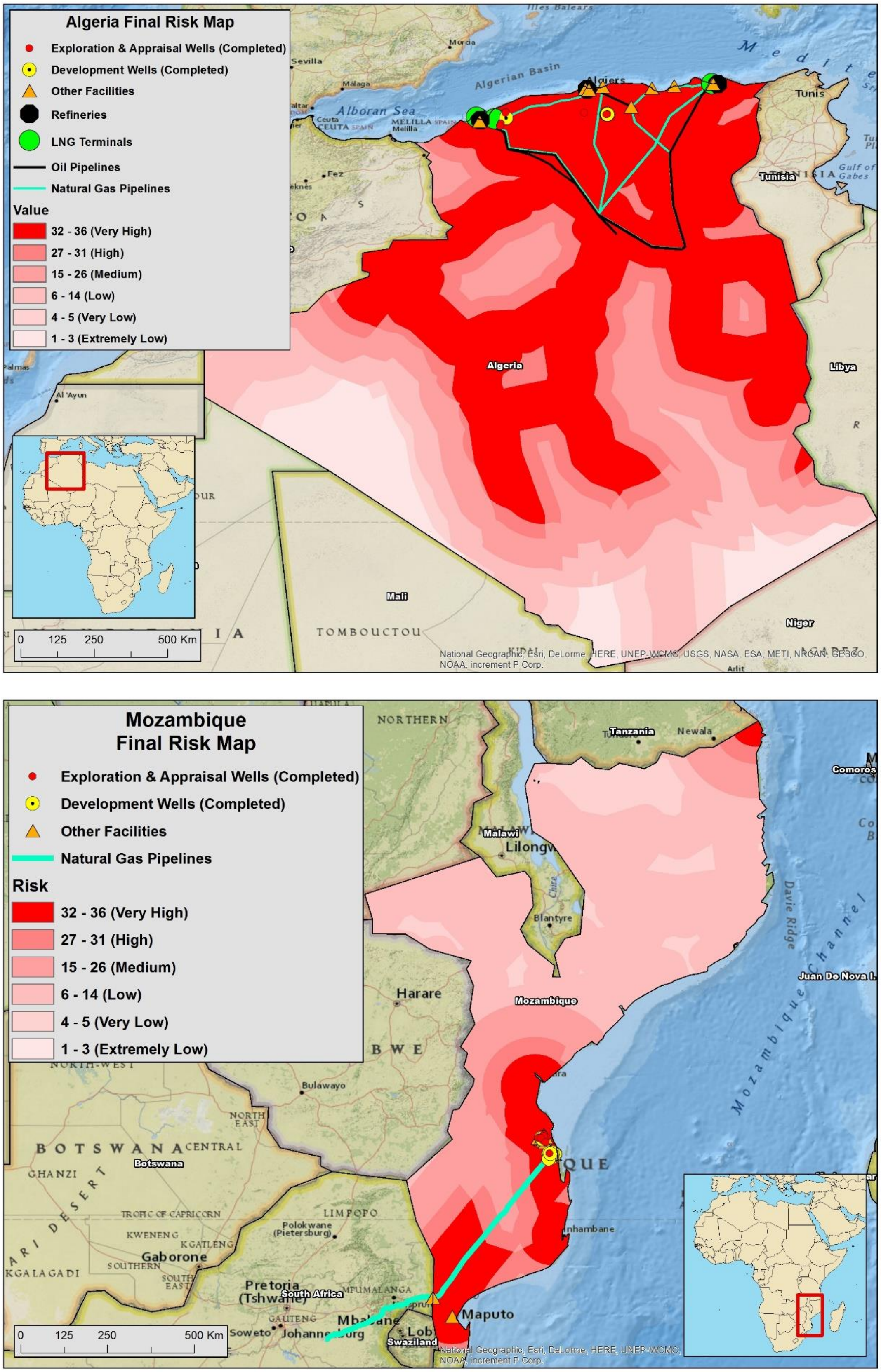


Figure 6-15: Final risk maps for Northern Algeria and Southern Mozambique

Next, a verification using percent correctly classified was conducted, similar to the one performed on the continental risk maps. One hundred percent of the total points (7) fell within the top class for risk: 32-36 (Very High). This means that when the previous risk methodology was applied to more detailed, current data, similar results were observed. This lends credibility to the model used at the Africa continent level. A map of the risk verification is shown below (Figure 6-16).

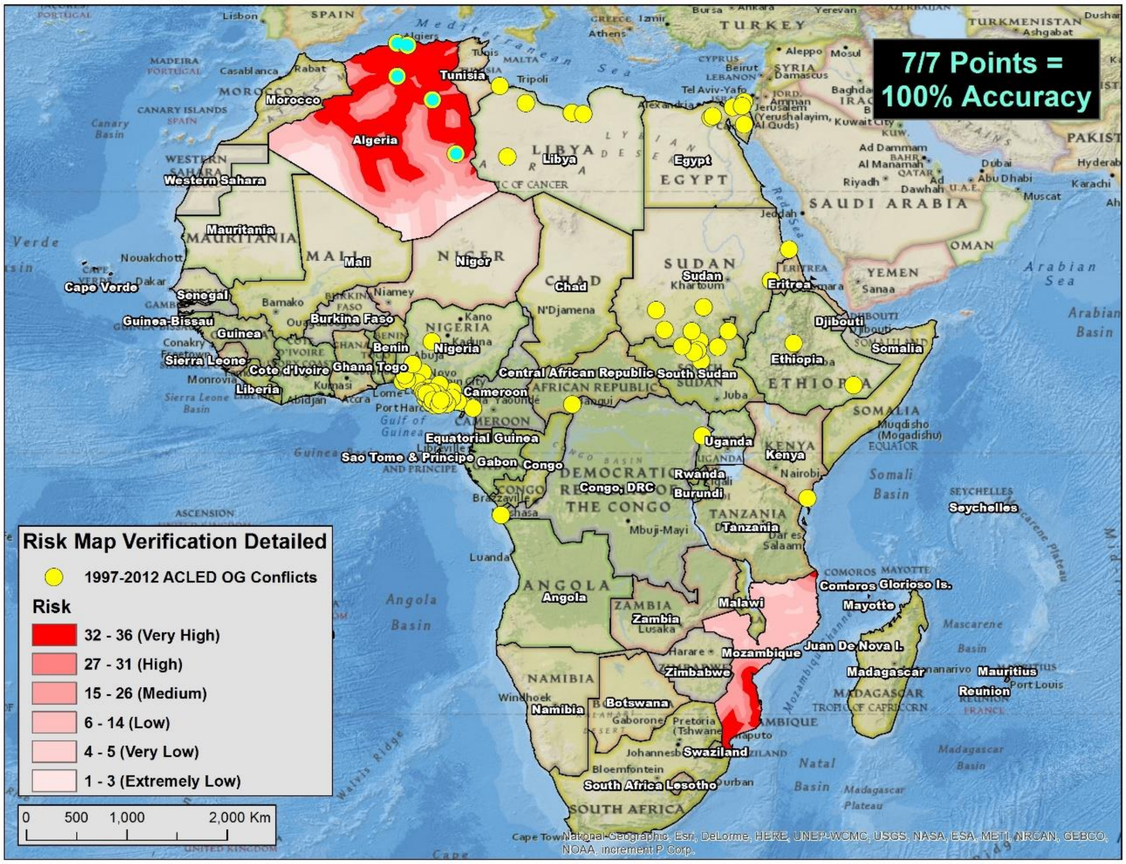


Figure 6-16: Verification for detailed data

6.3 Web Mapping Application

A web-based mapping system was an easy way for the client to access both the input data and output results. Since the client had little GIS knowledge, a user friendly, aesthetically pleasing interface was designed with several basic tools. This application is accessible to anyone with proper credentials and an internet connection, and is secure, reliable, and accessible on most mobile devices. The application is also easily customizable, since it is built using the ArcGIS Web AppBuilder (WAB) as opposed to other traditional methods of web application development such as ArcGIS API's for Javascript, Flex, and Silverlight. The WAB requires less time than traditional methods because the coding aspect is removed from the process. It is worth noting that the WAB is extendible. This means that the existing code can be modified and added to if necessary. Such work was not required by the client for this project. In the event that the client decides they would like to change the interface, widgets, or layers, this is possible with little to no coding.

The WAB interface is shown below (Figure 6-17), which includes examples of the possible customizable widgets that are able to be quickly and easily configured.

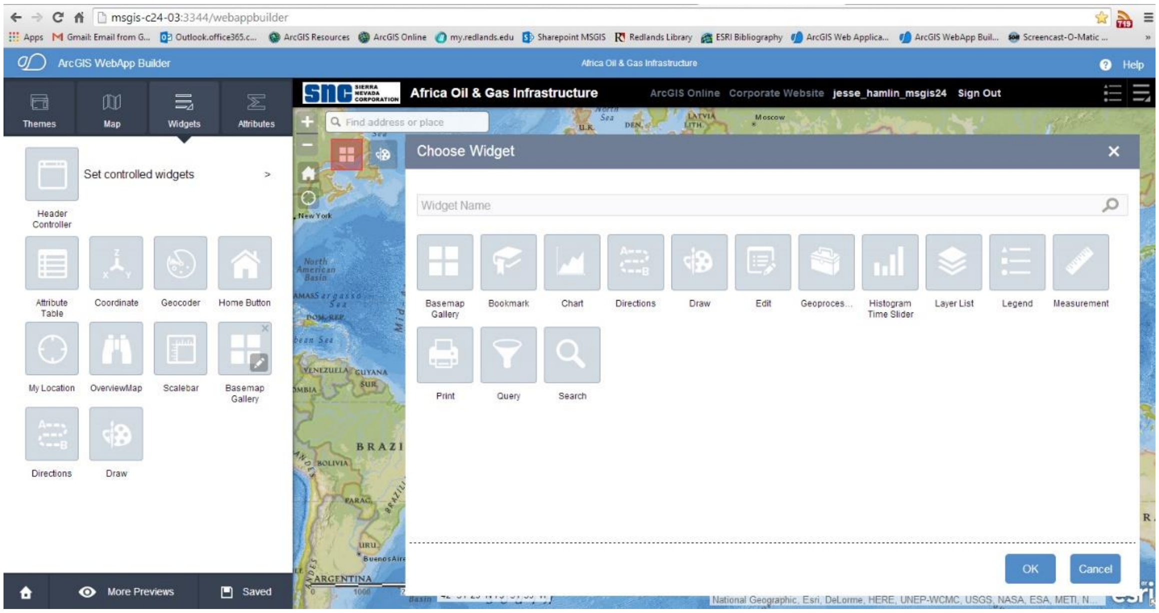
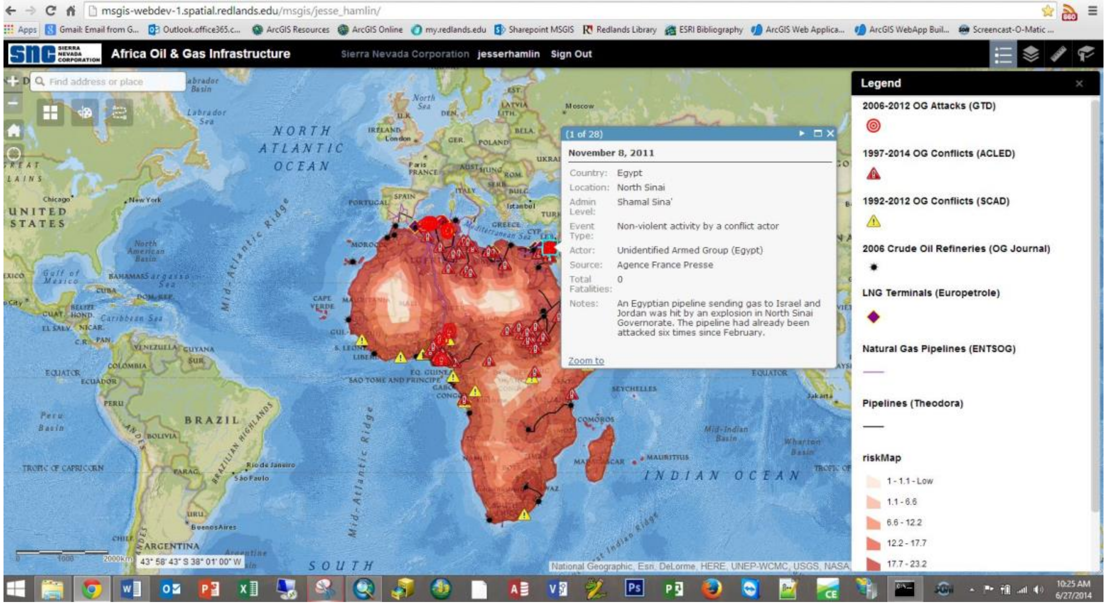


Figure 6-17: Web AppBuilder pre-loaded widget options

Figure 6-18 illustrates a working version of the application. This contains a display of the overall design, several layers, and a pop up for an OG event from November 8, 2011, in which an Egyptian pipeline was attacked by an unidentified armed group.

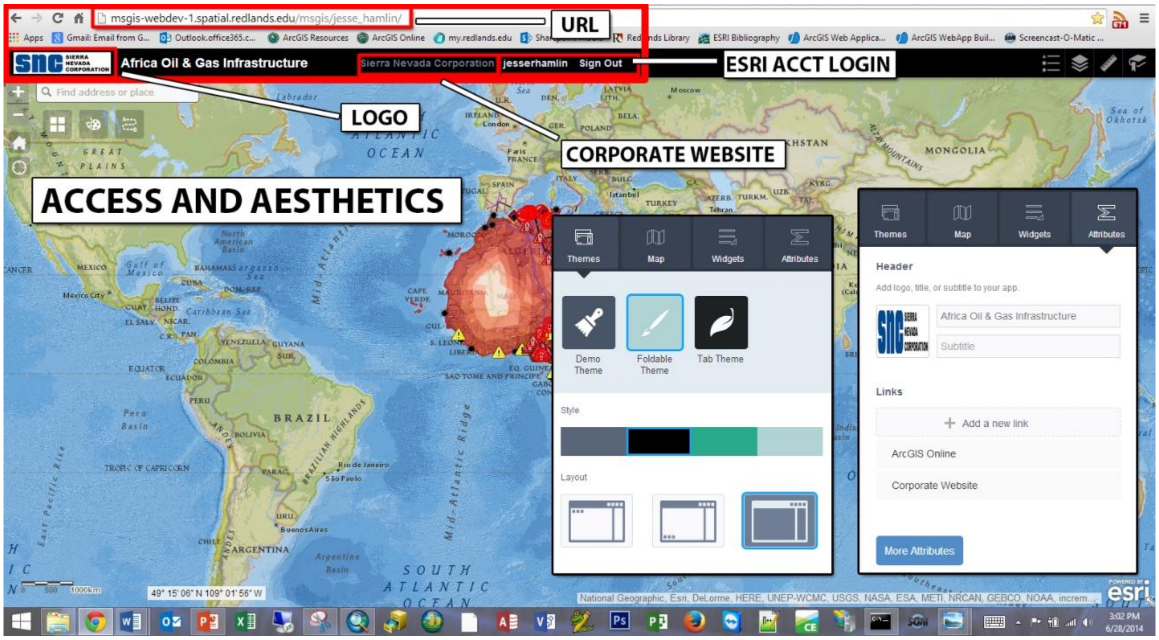


November 8, 2011

Country: Egypt
Location: North Sinai
Admin Level: Shamal Sina'
Event Type: Non-violent activity by a conflict actor
Actor: Unidentified Armed Group (Egypt)
Source: Agence France Presse
Total Fatalities: 0
Notes: An Egyptian pipeline sending gas to Israel and Jordan was hit by an explosion in North Sinai Governorate. The pipeline had already been attacked six times since February.

Figure 6-18: Screenshot of web application

In terms of individual widgets, the client's only requirement was to be able to view the data and bring up information via pop-ups for different layers. However, several widgets were built into the application for convenience purposes. These included widgets for tools such as the ability to zoom, perform measurements, bookmarks, coordinates, zooming to one’s current location, and retrieving different basemaps. The first set of tools that will be discussed are regarding access and aesthetics. An Esri global account was required to access the application. A corporate logo and link to the client’s corporate website were included. An appropriate theme was chosen. The WAB contains options for adding and selecting all of these without any programming (Figure 6-19).



Header

Add logo, title, or subtitle to your app.

Africa Oil & Gas Infrastructure

Subtitle

Links

ArcGIS Online

Corporate Website

Figure 6-19: Access and aesthetics tools of the web mapping application

The next set of tools are navigation and basic tools widgets. This includes tools such as a geocoder, directions, drawing, basemaps, zooming, home, current GPS location, and coordinates. The geocoder allows the user to select a location on the earth’s surface using common place names, similar to common web mapping websites such as Google Maps. This allows the client to zoom to particular locations on the African continent. The directions widget allows the user to enter start and end place names which then creates a drive time and distance, also similar to Google Maps. The drawing widget allows the client to create simple mark-ups on the existing maps for illustration purposes. The basemaps allow the client to change different ArcGIS Online basemaps and display satellite and terrain information. The zoom, home, and my location widgets are standard tools that allow the user to zoom, set the map extent to the continent of Africa (configured by the author), and determine current location. The coordinates widget display coordinates of the current map extent in decimal degrees or degrees minutes seconds. All of these widgets were designed using the pre-loaded templates included with the WAB (Figure 6-20).

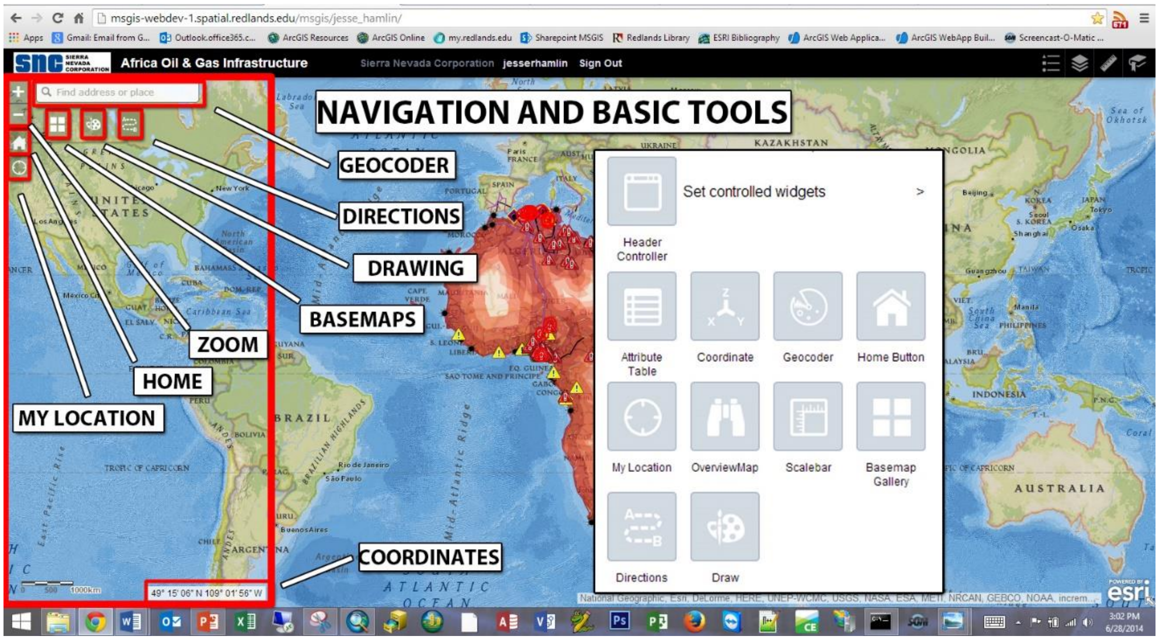


Figure 6-20: Navigation and basic tools of the web mapping application

The last set of widgets were layer and bookmarks tools. This included standard legend, layer, measurement, and bookmarks tools. These allowed the client to turn on and off different layers, change draw order, compute areas (in acres, square miles, square meters, and hectares) and distances (in miles, kilometers, meters, feet, and yards), and create their own map extent boomarks from which they could zoom to and save for future reference. All of these widgets were created and configured using standard templates included with the WAB (Figure 6-21).

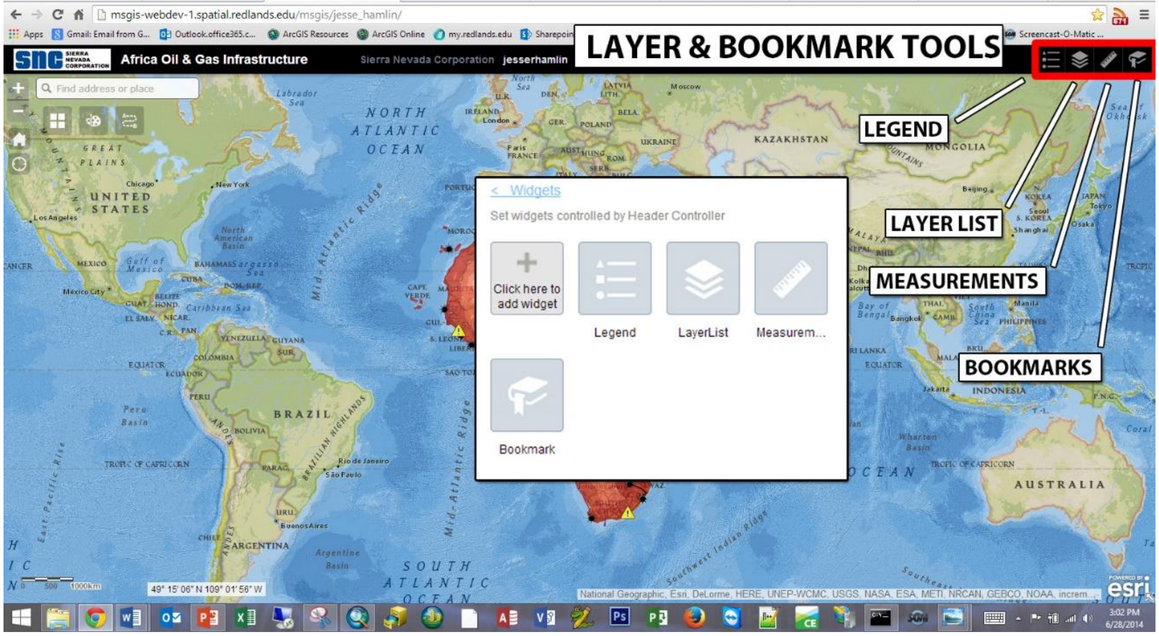


Figure 6-21: Layer and bookmark tools of the web mapping application

The web mapping application is also viewable on most mobile devices, including Apple iOS and Android devices. Devices tested for this project included the iPad 3, iPhone 4s, and Samsung Galaxy S4, which were all able to successfully access the application. However, there were minor performance issues with all three devices, which included application responsiveness and interface layout. This was to be expected, because the application is a URL-based web mapping application, it is not built to provide an ideal user experience for mobile devices. In order for this to take place, a native application would need to be designed for the specific operating system and uploaded as an app to the iTunes (iOS) or Google Play (Android) store. This would require large amounts of custom coding in languages not familiar to the contractor (i.e., Objective C for iOS or Java for Android). For this reason, the web mapping application should be accessed primarily by non-mobile applications.

6.4 Summary

In conclusion, the creation of a geographic database will be useful for the client. Prior to this project, the client had little to no spatial information available. In addition, using the risk analysis created for the project, the client now has another source in which to understand better where attacks are occurring and where vulnerabilities are present. According to the risk analysis, these include countries such as Nigeria, Algeria, Libya, Egypt, Somalia, and Sudan. An area for future improvement could be to acquire more detailed, current data for larger geographic areas. In terms of the web mapping application, the client is now able to access, view, and upload information. This will allow them to understand where infrastructure is located, but also where threats are most often present.

Chapter 7 – Conclusions and Future Work

7.1 Conclusions

The main requirements for this project were to assemble a spatial database for the client, perform geospatial analysis concerning high and low risk areas, and to present all of this information to the client in a single interface. All requirements for this project were met and the client was satisfied. Spatial information was researched and acquired through various means including free data and data purchased by the client. A spatial database was then assembled using this information and standardized, and then provided to the client for future work. Research was conducted on spatial risk methods and a selected literature was chosen. From here, spatial analysis was conducted at two different levels: low scale continental analysis for Africa, and also detailed analysis for the countries of Algeria and Mozambique. Verification of this analysis also took place via three different methods. Three output layers were generated for the client pertaining to high and low risk areas for OG infrastructure attack and theft. A web mapping application was then constructed, designed, and tested to meet the client's needs. This included not only the abilities to view and upload datasets, but also to use common web mapping tools such as panning, zooming, basemaps, measurements, bookmarks, and other tools. The application was also accessible by various mobile devices. All functional and non-functional requirements were met.

When looking at the risk assessment component of the project, the OG infrastructure risk model yielded some interesting results. The highest rate of risk occur in countries where both infrastructure (hazard) and human variables (vulnerability) are present. In other words, both hazard and vulnerability must be present in order for risk to be severe. This is due to the multiplication methods used. This is one of the main reasons why countries that not only have large amounts of OG infrastructure, but also have human vulnerabilities (e.g., presence of terror networks, large amounts of social unrest, high populations and advanced road networks), will exhibit the largest amount of OG infrastructure risk. This is true for countries such as Nigeria, Egypt, and to a lesser extent for Algeria and Libya. However, just because a country does not have existing infrastructure or resources (e.g., Somalia), does not mean there will necessarily be an absence of risk. In Somalia's case, risk still exists because there is always the possibility that oil and gas reserves will be discovered and subsequent infrastructure will be constructed. This is because Somalia has high levels of social unrest and the presence of terror groups. Similarly, South Africa has high levels of risk because of its advanced road infrastructure and high population. All of these variables were used as inputs in the risk model.

In terms of improvements, more detailed, accurate, current data for larger areas would be useful. The detailed data acquired could be considered more accurate and was definitely more current, the spatial extent of the data was small. The free data acquired was for a much larger extent, but the accuracy, validity, and currency of the data were questionable. This is because the data came from multiple unaudited sources. Unfortunately this was a requirement for the project as data is difficult to acquire for the

African continent. The more detailed and accurate the inputs are for a spatial risk model like this one, the more likely the outputs are to be accurate.

7.2 Future Work

There are several opportunities for future extensions to this project, given additional time and resources. The first addition to this project could be the ability to monitor OG infrastructure and assets. One of the ways this is possible is with Really Simple Syndication (RSS) and GeoRSS feeds. RSS feeds offer real-time internet feeds to regularly published information, such as news feeds and blog entries. GeoRSS feeds are RSS feeds that are georeferenced or spatially enabled. This allows mapping applications to publish the locations of these feeds in real time. As of June 28, 2014, ArcGIS Online supports the addition of GeoRSS feeds through a simple online link. One problem is that GeoRSS feeds for the topic area of this report were difficult to find. Another option would be to find a suitable RSS feed, available in many places on the web, and write a program that queries, retrieves, and converts commonplace names to coordinate information, for example geocoding.

Another possible add-on to this project could be to create a native application for mobile devices. Currently the application is accessible by mobile devices; however, the performance is slow because the ArcGIS WebApp Builder was not constructed explicitly for mobile devices. Through the creation of a native application for Apple iOS (C Sharp) or Android (Java), a better user experience on mobile devices would be possible. This would not only allow the information to be viewed in the office, but also in the field and on the road if necessary.

Additional future work could be to create a tool in either ArcGIS Model Builder or using a python script. This tool would allow the user to run the risk model and adjust weights for each of the individual variables. This would permit users to re-run the risk analysis using different or updated datasets and adjust the weights. This would let the client run quick analyses on the fly. It would also allow the user quick options for tackling the issue of spatial dependency. The nature of geographic data for several of the variables used in this model is that some variables may be directly or indirectly influencing others. An example is that in most parts of the world, the presence of urban areas is often found in near proximity to the presence of major highways (two of the variables used in the risk model). By having the option of being able to adjust weights for each of the variables on the fly, the user may get a better sense of which variables are truly dependent on each other and which are not.

Another addition is to build a more suitable uploader widget for the web mapping application. Currently, the WAB does not contain an uploading widget. Instead, the client has to sign into AGOL and upload and configure spatial datasets from there. It would be useful for the client to be able to upload this information from the web mapping application itself. Possible options for this would be to create a geoprocessing tool using ArcGIS Server and WAB and publish it as a widget, or to modify the existing web mapping application JavaScript and Dojo code.

The last addition would be to obtain higher quality detailed data. The data purchased is missing information on pipeline size. Larger pipelines would in theory be more attractive for potential attackers to target. Also, the dataset is missing information on whether pipelines are above or below ground. This would be useful because an above ground pipeline is in theory a more attractive target than an underground pipeline, because it is difficult to locate underground pipelines and requires additional work to do so. Lastly, the spatial accuracy of the information is somewhat in question. For example, pipelines do not connect directly to facilities, instead running through or near them. Higher quality data would contribute to a more reliable analysis.

7.3 Summary

It was the goal of the author to explain the process behind this project. Mapping existing OG infrastructure, determining areas of high security risk, and visualizing the information were the major goals of the project. All goals were accomplished and several opportunities for future improvement were identified.

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Appendix A. Risk Analysis Workflow

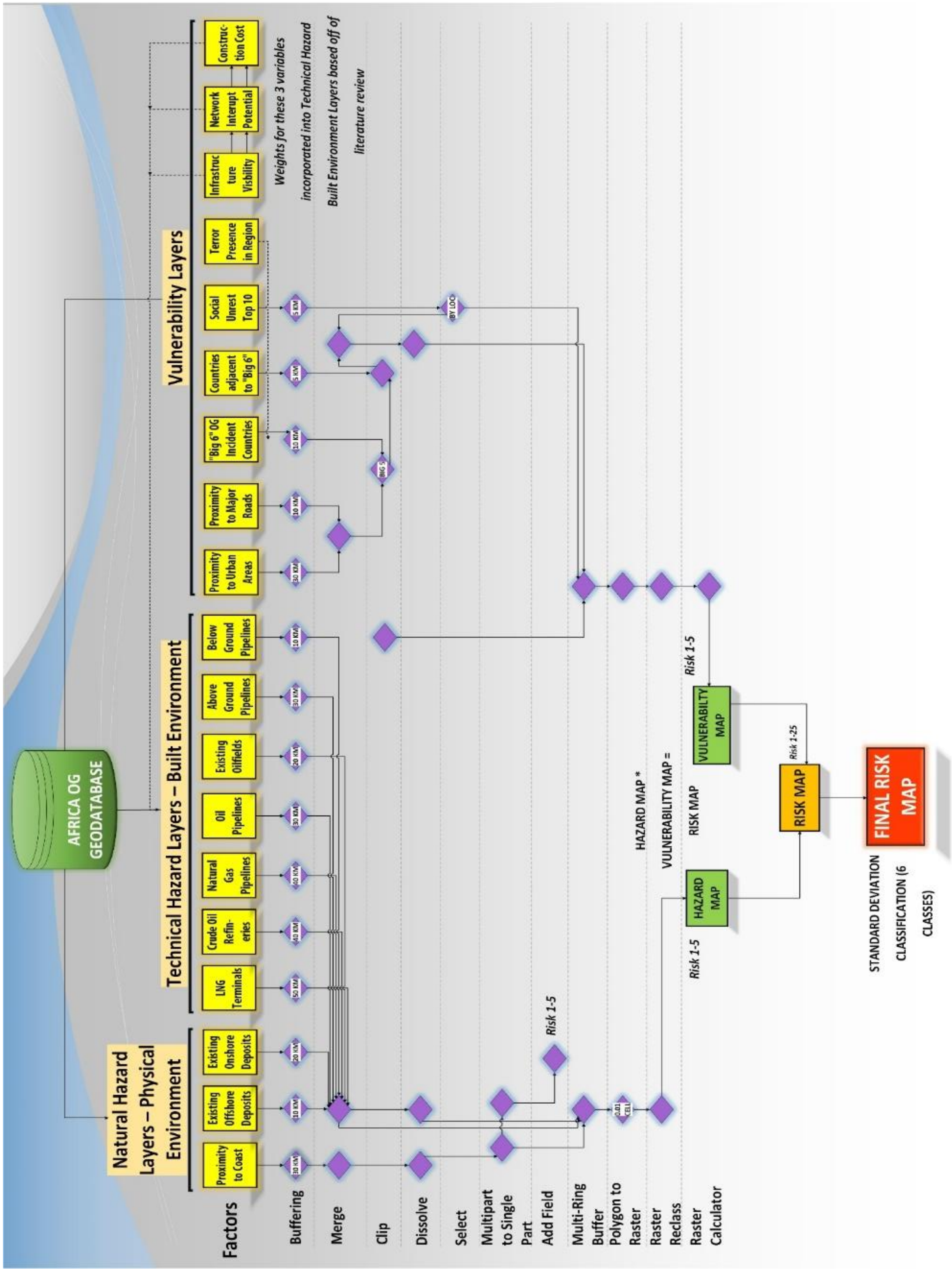

Figure A-1: Overall risk analysis workflow