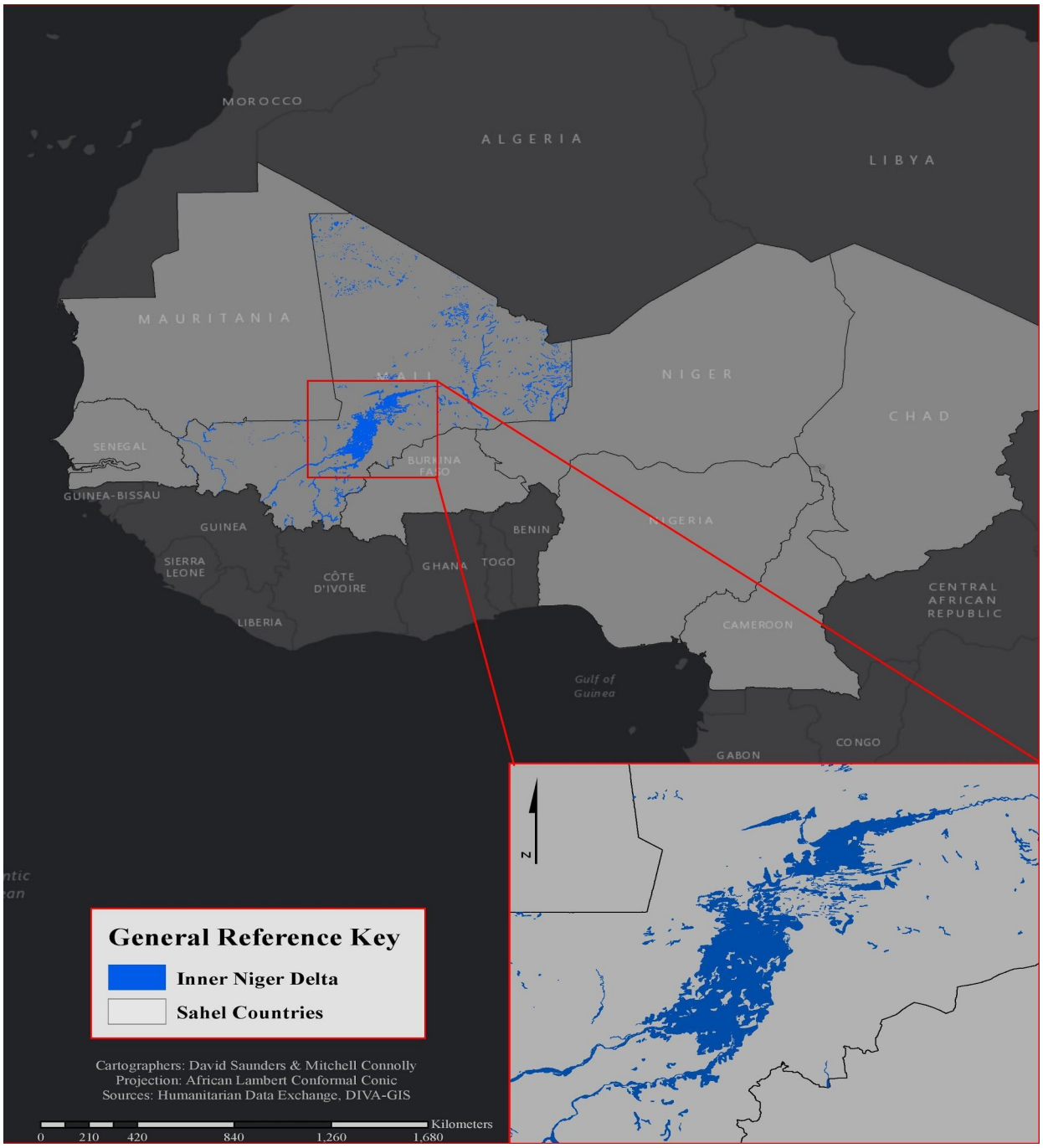
Development of Geospatial Indicators for the Analysis of Food Security in West Africa
by David Saunders & Mitchell Connolly



The Inner Niger Delta, located in central Mali, is the largest seasonal floodplain in West Africa and provides a lifeline for roughly 2 million people[1]; this delta is of vital importance as it provides water for agriculture, fishing, livestock, and trade in the Sahara. With 65% of its land being classified as desert or semi desert [2], and 80% it's labor force engaged in farming and fishing practices[3], food production is the most important sector in Mali's economy. However as the river floods seasonally, the Inner Niger Delta is not a year long resource; during a productive season the area can exceed 25,000 km^2 but recent droughts caused the area to grow less than 5,500 km^2[4]. With a 94% decline in rain between 1950-2003, half the floodplains are no longer productive today[5], straining the country's already fragile economy.

The growing scarcity of food and water resources in West Africa will exacerbate conflict, force large population movements, and disrupt the global economy, straining US foreign policy goals. To achieve US foreign policy goals of good governance, peace, stability, and sustained economic growth across Sub Saharan Africa it is essential to develop effective methods of predicting and monitoring food insecurity. To meet this need we have used the Inner Niger Delta in Mali as a study area to develop a set of signatures that can be used to analyze stability and food security.

Geospatial indicators have been historically been used to identify potential food insecurity hotspots; however, most of these indicators have been either based on unreliable and difficult to obtain ground reports or have failed to take into consideration the wide range of multidimensional issues at play. Effective indicators are needed to fully understand why one of the most agriculturally productive area in West Africa is experiencing food insecurity. We have carefully identified seven indicators, taking a multi-faceted approach toward analyzing this food insecurity issue. By using the proposed indicators, food security assessments can be done more effectively and efficiently by allowing analysts to simply identify if food insecurity markers exist in their study area.

1. Current food sources under threat from disruptive forces (i.e climatic forces, conflict)
2. Potentially productive land covers being underutilized and mismanaged?
3. Areas displaying significant seasonal changes in vegetation health
4. Areas displaying significant changes in water absorption
5. High populations with stressed food accessibility, availability, or utilization
6. Ineffectual ingestion and distribution of vital food sources
7. Violent conflict in close proximity to key infrastructure, food production, or population sites

---

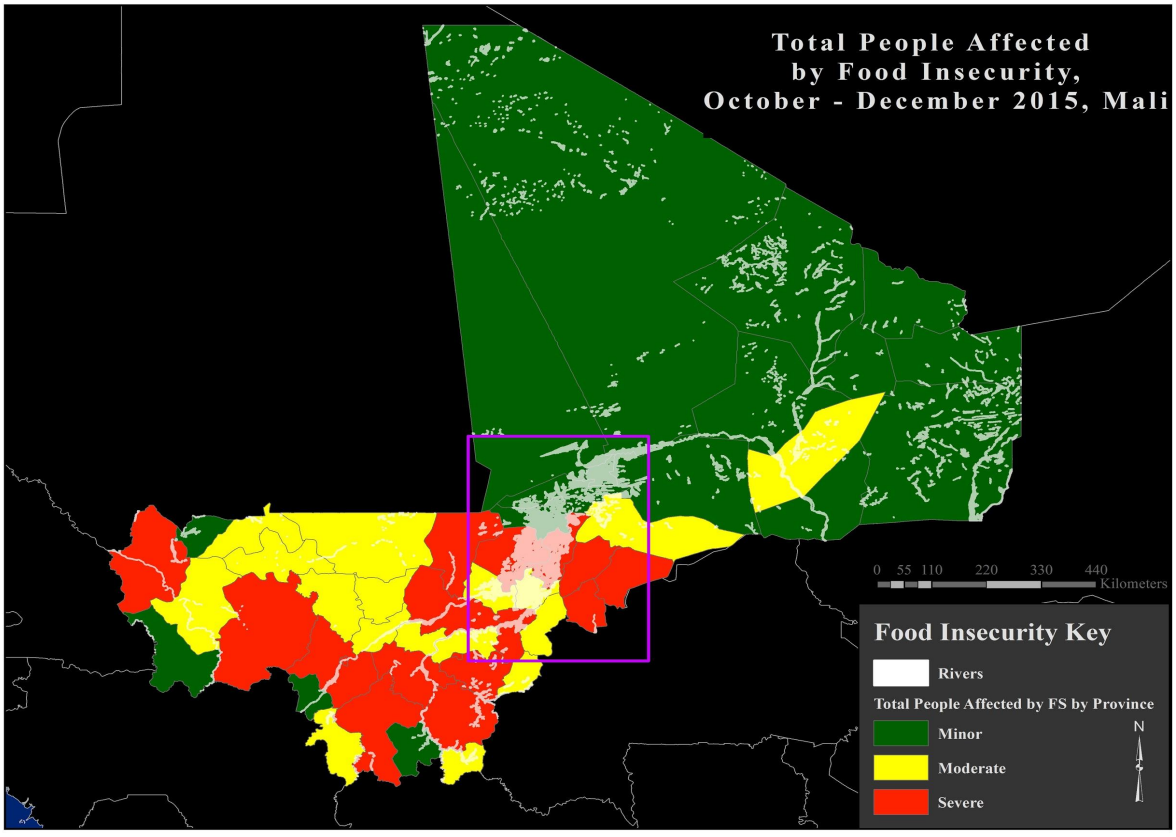
[1] Camballo, Paula. "The Niger River Delta - a Strategic Asset in Africa's Sahel Region". *The World Bank*. 10/20/2014.
[2] "Inner Niger Delta Flooded Savanna." *Inner Niger Delta Flooded Savanna*. World Wild Life Fund, n.d. Web. 15 Mar. 2016.
[3] "Mali Economy Profile 2014." *Mali Economy Profile 2014*. N.p., n.d. Web. 16 Mar. 2016.
[4] "State of the World's Birds." *Birdlife Data Zone*. N.p., n.d. Web. 15 Mar. 2016.
[5] Ajayi, Oluyede, Noumou Diakité, Aly Konaté, and Delia Catacutan. "Rapid Assessment of the Inner Niger Delta of Mali." (2012): n. pag. Web.

Method	Indicator	Significance
Normalized Difference Vegetation Index **Macro level**	Areas displaying significant seasonal changes in vegetation health	Change in vegetation health/ diversity/abundance Climate Change effects Deforestation Drought Areas easily/ often disrupted
Evapotranspiration Levels **Macro level**	Areas displaying significant changes in water absorption	Water availability/ use Crop yields Drought Potential resource conflict areas
Population Dynamics **Macro level**	High populations with stressed food accessibility, availability, or utilization	Population movements due to conflict, environmental refugees, and drought Populations at risk Degree of demand for food and water
Land Cover - Land Use Classification **Macro level**	Area being used for food production (or loss of that site) Potentially productive land covers being underutilized, mismanaged	Loss of an area that is important for food security. Mismanagement of resources and land area
Livelihood Classification **Micro level**	Current food sources under threat from disruptive forces (i.e climatic forces, conflict)	How each area survives/ provides for itself Food sources available/ not available at given time
Infrastructure Analysis **Micro level**	Ineffectual ingestion and distribution of vital food sources	Storage capacity Food accessibility Market opportunities Ability to ingest and distribute food effectively
Conflict Analysis **Micro level**	Violent conflict in close proximity to key infrastructure, food production, or population sites	Connections between methods Potentially disrupted food - distribution Loss of resources Areas in need of aid

Table 1. Geospatial Markers: This table lists the proposed indicators, the methods that were performed and the significance of each indicator.

Research Question

The ability to see food insecurity indicators through maps is of vital importance to the Intelligence Community as it provides an easy to understand visualization that communicates an issue with little cost and time. The goal of our analysis is to create a meaningful set of signatures to help analyze food security and stability utilizing open source and geospatial intelligence. We selected the Inner Niger Delta as it provides an ideal study area to analyze the links between climate vulnerability and change, food resources, human security, conflict, and adaptation. We hope to demonstrate that, by using our indicators and methods analysts can identify areas of possible food insecurity, confirm the existence of such insecurities, and monitor or assess the degree of crisis.



Map 1: Data was provided by the Humanitarian Data Exchange, a leading provider of open source humanitarian GIS data. The Humanitarian Data Exchange has been used significantly throughout this analysis and its importance in assessing food security crises will be discussed in the results shown [6]

[6]"Mali: 2015/2016 Food Security IPC Analysis." *Humanitarian Data Exchange*. N.p., 07 Dec. 2015. Web. 04 Apr. 2016. <https://data.hdx.rwlabs.org/dataset/mali-2015-2016-food-security-ipc-analysis>.

Justification

With an 80% reduction of water flow during the non-rainy season, the delta is characterized as a seasonal oasis in a barren land, giving good reason to be designated a Ramsar Wetland Site of International Importance[7]. Most of the population of ancient Mali made their living just as they do today, in agriculture[8] , yet within recent history the situation has deteriorated drastically. The wet season no longer brings promise of, at least temporary, food security as global environmental change, dwindling water supplies, conflict, and ineffectual resource management for a growing population has left much of the Inner Niger Delta in a state of disarray. Between 2012 and 2013 alone, 3,500 Malians citizens were killed in Northern and Central-Delta Mali[9], where drought and food insecurity concerns are highest.

It is important to note that Mali's future is not the only one threatened by its internal violence and instability; multi-dimensional problems such as water scarcity, food insecurity, and conflict often transcend political boundaries. The Inner Niger Delta has already seen environmental refugee movements and mass migrations to equally insecure and environmentally vulnerable neighbors, furthering conditions of poverty, political instability and conflict in the region. As of December 2014, the 60,000 Internally Displaced People who fled northern Mali conflict and food insecurity in 2012 and 2013 have still not secured a suitable solution to their displacement[10]. In November of 2015, the number of Malian refugees in Niger reached its highest level, with over 57,000 refugees fleeing Mali due to food shortages, conflict and unfavorable farming conditions[11]. Keeping in mind that 90% of Mali's population lives in the southern region close to the Delta[12] and that millions of cattle herders, fishermen and farmers flock this area from neighboring countries during the productive season, it is clear that agricultural productivity in Mali plays a large role in the regional stability of West Africa. The Inner Niger Delta is thus a strategic and vital ecosystem that provides resources for inhabitants in an nearly uninhabitable environment; without it, conflict and violence will ensue with negative effects reaching far past Mali's borders.

The necessity to provide the growing population with a sustainable nutritious supply of food has proven to be difficult. But the problem goes far beyond this singular issue; currently there is a lack geospatial

---

[7] "Water crisis in the Inner Niger Delta (Mali), Causes, Consequences, Solutions." *A&W Ecological Consultants*. 24/11/2012.
[8] "Mali Breakout - Geography." *Mali Breakout - Geography*. N.p., n.d. Web. 16 Mar. 2016.
[9] "Northern Mali Conflict." *War Statistics*. N.p., n.d. Web. 31 Mar. 2016.
[10] "IDMC » Mali IDP Figures Analysis." *IDMC » Mali IDP Figures Analysis*. N.p., n.d. Web. 31 Mar. 2016.
[11] "Number of Malian Refugees in Niger Reaches New High." *UNHCR News*. N.p., 10 Nov. 2015. Web. 31 Mar. 2016.
[12] "Mali." *World Vision*. N.p., n.d. Web. 31 Mar. 2016.

indicators that target the main causes of food insecurity. The data that is currently available for use is often based on ground reports and can be difficult to obtain or does not holistically depict the sources of the problem. Important data collected at ground stations includes measurable variables such as rain fall estimates, transpiration levels and soil moisture. However due to Mali's lack of infrastructure, these locations are often run down and are not kept in condition to collect data making measurable environmental data difficult to obtain.

In addition to the neglect of these base stations, previous studies have failed to take into a wide range of multi-dimensional issues that is currently at play with Mali. Previous studies place a heavy focus on environmental factors when analyzing climate change and food insecurity in Mali, failing to consider social, political and economic factors that are currently at play. Results are thus limited and do not truly grasp Mali's issues. Mali's concerns go far beyond climatic factors with non climatic factors influencing instability and violence. Our proposed list of indicators were created with a multi-dimensional awareness, taking into consideration a wide range of factors at play including environmental, social, economic and political dimensions. Our proposed indicators create a more holistic approach that will be more meaningful to U.S national security initiatives.

As global issues become increasingly difficult to monitor, the United States' resources are being strained and the ability to detect and monitor multi-dimensional and measureable variables without the need for ground reports or extensive human resources is becoming increasingly valuable. This means that the US government can spend time and money more efficiently and effectively without overinvesting. Remote sensing is thus an important application as it provides the opportunity to analyze and monitor patterns and trends through remotely sensed imagery.

Methods

Normalized Difference Vegetation Index

Measuring vegetation health, abundance and diversity is also used to accurately assess crop security and distribution. We propose that a Normalized Difference Vegetation Index (NDVI) is the best method for this. A remote sensing index is a manipulation of the pixels in a remotely sensed image that produces something meaningful to the user (in this case the variable of interest being vegetation health, abundance and diversity). Indices are widely used in remote sensing as the process to create the final product is simple, non time consuming and effective for decision making[13]. Vegetation indices are widely used to look at the extent of agriculture in a region and are useful in identifying areas of high stress and potential crisis by showing areas that have a high concentration of unhealthy crops[14]. Consequently, the final product of our NDVI shows the user these three variables: vegetation health, abundance and diversity. This a great method for our analysis as it allows for active monitoring of the agriculture in the Inner Niger Delta. By comparing annual NDVI's during the same season, we are able to determine the direction of vegetation change, allowing us to identify long term trends rather than short lived anomalies. However, vegetation anomalies can be identified to determine the specific rate of change from the previous year. These vegetation differences will provide the most meaning to the end user as an indicator of drought and climate change. Annually declining NDVI's naturally indicate that larger environmental factors such as global warming, deforestation and large scale drought are at play and allow for the identification of areas which are easily or often disrupted from such multi-dimensional factors. Similar analysis with vegetation health has been used in the past to monitor food insecurity in the Inner Niger Delta as the amount of vegetation shown near the delta correlates to the amount of grown agriculture. Because of this, we feel confident that this indicator will be useful and easy to interpret as its results have a clear connection between a wide range of climatic related factors previously listed.

Evapotranspiration

The next geospatial method we propose to be analyzed during or prior to a food security crisis is Evapotranspiration (ET). Evapotranspiration levels show the amount of water absorbed in vegetated areas and are an ideal method of measuring healthy vegetation and soil[15]. This method has been widely used

[13] "Remote Sensing Phenology." *Remote Sensing Phenology*. United States Geological Survey, 12 Jan. 2015. Web. 03 Apr. 2016.
[14] "Remote Sensing Methods." *The Landscape Toolbox*. 07 Oct. 2013. Web. 03 Apr. 2016.
[15] "Chapter 1 - Introduction to Evapotranspiration." Natural Resources Management and Environment Department, Food and Agriculture Organization (FAO), n.d. Web. 03 Apr. 2016.

in studies of environmental variables in Africa as it provides an additional dimension that vegetation indices cannot. Knowing the crop type of an area, ET levels are used to monitor whether crops are receiving the appropriate water inputs. This helps to paint a more complete picture of the situation as this information can be used to predict crop yields, and to monitor the degree and effects of drought. A high availability of water from rain and floodplains will naturally increase the rate of plant transpiration and evaporation, indicating crop health, while lower absorption levels indicate a lack of water. By determining how much water is present, inferences can be made about the resulting degree of food security in a specific area. Yearly measurements are vital as ET's indicate drought, crop yields, rising temperatures and potential resource conflict areas, four critical factors that are currently decimating agricultural production and raising food security concerns[16]. Monitoring resource availability with knowledge provided by other methods such as population dynamics allows for indication of where conflict may occur by identifying "hot spots" where dependence on vulnerable or dwindling resources is high. Due to this, we suggest that areas showing significant changes in water absorption be monitored carefully on year to year basis.

Population Dynamics

The next indicator we propose to analyze is population dynamics as it provides a deeper understanding of the complex interconnectedness of the issue and allows for more holistic solutions. In terms of large scale social dynamics, analysis of population adds meaning to the movements of people due to conflict, economic, or environmental factors. With lowering water levels, due to usage beyond Mali's borders and dams upstream, it becomes important to assess whether the delta can support its growing population. Although more difficult to monitor using remote sensing, general GIS humanitarian and population data can extremely useful in addressing where food insecurity in prevalent. Because food insecurity is most devastating to large populations, we decided to focus our analysis on the delta as Northern Mali simply does not see high enough concentrations of people. In contrast, the delta sees one of the highest concentrations of people per area in West Africa making it an appropriate study area. By observing where people live in relation to the delta and assessing the supply demand dynamics analysts can identify those populations which have stressed food access, availability, or utilization.

[16] Senay, Gabriel. "U.S. Department of Interior." *FEWS NET Energy-balance Modeling of Actual Evapotranspiration (ETa) For More Accurate Drought Monitoring*. N.p., n.d. Web. 18 Feb. 2016.

Land Use-Land Cover Classification

Flooding once a year and growing up to 7.5 times larger during the rainy season, the Inner Niger Delta is a lifeline for Mali, providing productive agriculture and pastoral land use[17]. The area has roughly 416,0000 square kilometers of agricultural land cover making it 16th in the world in terms of arable agriculture hectares per capita[18]. But how much of this land cover is utilized and managed to its full potential? To get a better understanding of Mali's ability to be adaptive toward climatic and non-climatic factors we propose that Land Cover-Land Use Classification data be used. By distinguishing different types of land cover such as agriculture, water, trees, barren land and developed land, it is possible to observe human activities and the management of land and resources. In the case of Mali, a land cover analysis is extremely useful as it shows the distribution of areas that are agriculturally productive and areas that are not suitable for such growth. Our land cover analysis focuses on one major geospatial indicator: where potentially productive land cover is being underutilized and mismanaged. By identifying unproductive land cover that is near the Inner Niger Delta or that is in close proximity to other agriculturally productive sites, we see that Mali is not taking full advantage of its land cover. Our method involved identifying significant amounts of sparse vegetation near the delta in an effort to determine whether these areas are more vulnerable to climatic changes or if they are merely being mismanaged. If land cover change is not collected on a year to year basis Vegetation Indices and Evapotranspiration measurements should be be substituted, which will be discussed below.

Livelihood Classification

An analysis of livelihood zones reveals what food sources are currently available. A livelihood zone is an area of common lifestyle, food production or food sources. Before performing other remote sensing techniques, a livelihood classification should be performed as it will give general sense of how each area survives and provides for itself. By combining the results of livelihood classifications with other, more specific, techniques a more accurate depiction of food security is created. Combined results will show which food sources are under threat from disruptive forces such as climatic and conflict events. An example from our results is the identification of drought in an area that produces crops reliant on large quantities of water. This type of information will give analysts an understanding of what food sources will be available and thus if food security will be an issue for specific areas.

---

[17] Mockrin, Miranda, and Michele Thieme. "Africa: Mali." *WorldWildlife.org*. World Wildlife Fund, n.d. Web. 18 Feb. 2016.
[18] "Mali Agriculture Produce Stats: NationMaster.com." *NationMaster.com*. NationMaster, n.d. Web. 31 Mar. 2016.

Infrastructure Analysis

A holistic analysis of food security cannot be done without taking into consideration economic conditions and market opportunities. In terms of a geospatial indicator that assess these factors, we suggest analyzing infrastructure. Monitoring infrastructure allows for analysis of ingestion, storage, and distribution abilities while also taking into consideration the market opportunities that these factors influence. By analyzing these variables, we have concluded that assessing road conditions and infrastructure in relation to the Inner Niger Delta as well major population centers is useful as it provides knowledge of food accessibility and utilization. By utilizing imagery and data on infrastructure, we were able to create a clearer understanding of how well infrastructure is maintained and thus its effectiveness in providing proper transportation and distribution of food to necessary locations. Poorly constructed or damaged roads and buildings make moving and storing food difficult. Proper and well maintained infrastructure is key to effectively ingesting imports such as aid or distributing food from areas of surplus to areas experiencing food insecurity, which are often isolated or far from main population centers. Run down infrastructure simply cannot support large scale transportation operations, hindering relief efforts when food security, health, or environmental disasters occur unexpectedly. Thus, monitoring the state of infrastructure serves as an important method when assessing the abilities of an area to process, ingest, market, and distribute food effectively.

Conflict Analysis

Although conflict has always been difficult to monitor, it provides vital information into the social, political, economic and environmental issues at play in a complex and constantly changing system. Conflict is therefore a vital indicator when assessing the proximity of violent conflict locations to key infrastructure points, food production sites and population hotspots. Northern Mali has been devastated by conflict propagated by the Tuaregs, and Islamic extremists but as this conflict spreads to important agricultural sites near the delta it becomes even more important to monitor[19]. Conflict acts as a catalyst to food security as it disrupts food availability and accessibility by causing destruction to an already weak infrastructure. It can also disrupt the third variable of food insecurity, utilization, as food is too often used as a weapon, adding a dimension to the reinforcing cycle of conflict and food insecurity. As conflict moves south towards the Inner Niger Delta in an effort to maintain territorial dominance, food security

[19] Jublin, Matthieu. "Violence on the Rise In Mali as New Armed Group Emerges in the Central Region | VICE News." *VICE News RSS*. N.p., 16 Apr. 2015. Web. 03 Apr. 2016.

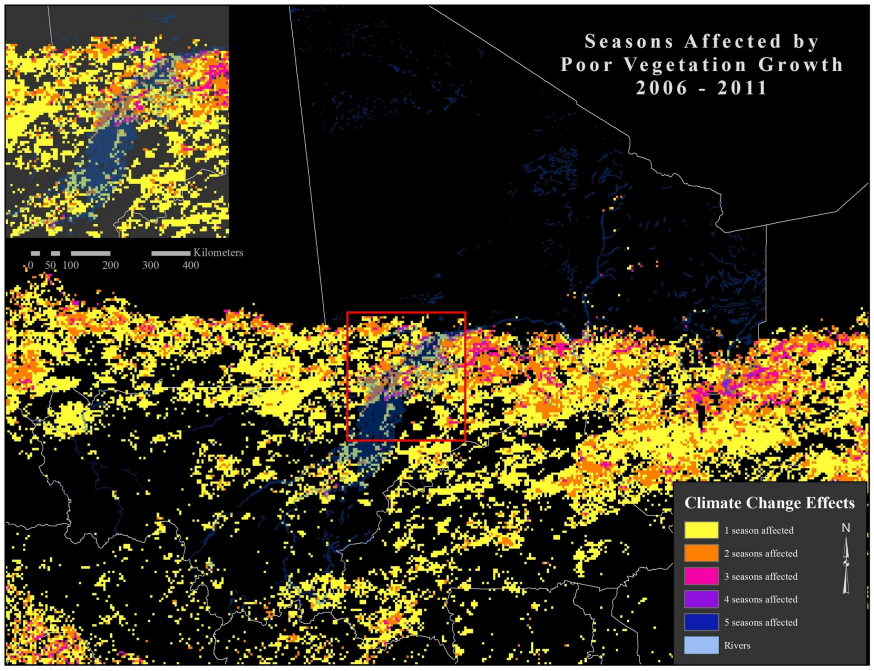
concerns in Mali, as well as the region, are compounded. This is one of the most agriculturally productive area in West Africa[20] and plays a vital role in the food security of the entire region. Potential conflict and food insecurity hotspots can be effectively identified by observing current conflict areas in relation to other connected factors such as population dynamics or key resource locations. By identifying potentially problematic areas analysts can provide decision makers with early warnings, allowing for preemptive actions or mitigation of negative outcomes with targeted aid.

[20] Kabii, Tom. "An Overview of African Wetlands." Ramsar Bureau, n.d. Web. 4 Apr. 2016

Results

Normalized Difference Vegetation Index

The next method that this report will focus on is the Normalized Difference Vegetation Index. Normalized Difference Vegetation Indices are used extensively in remote sensing as they provide a look into vegetation health and abundance. This method allows analysts to observe live vegetation and can be used for wide variety of analyses such as climate change, drought, deforestation, or in this case food security. These studies can be performed often, allowing for the visualization of changes over time. When performing food security studies analysts should identify areas which display significant seasonal changes in vegetation health. By looking at the same area, either multiple times within the same season or over several seasons, changes in vegetation health are made evident. When used with knowledge of an area or other methods this information can reveal an array of factors at play such as climate change, drought, and even conflict. Conducting an NDVI of an agriculturally productive area before and after the presence of a violent conflict may show a large decline in vegetation, indicating conflicts direct influence on food availability.



Map 2: Data is provided by the Sahel Food Crisis, a leading platform for sharing open GIS data on Food Security in West Africa.

The first vegetation index that was performed for our analysis showed the number of affected seasons by poor vegetation growth from 2006 to 2011. Provided by the Sahel Food Crisis, it is a regional ITHICA NDVI extracted from MODIS NDVI Time-Series[21]. This data shows the effects of drought and climate change on vegetation in the Inner Niger Delta over a 5 year period. The yellow color indicates that few seasons were affected, while orange, pink, and dark purple indicate a higher amount of effected seasons.

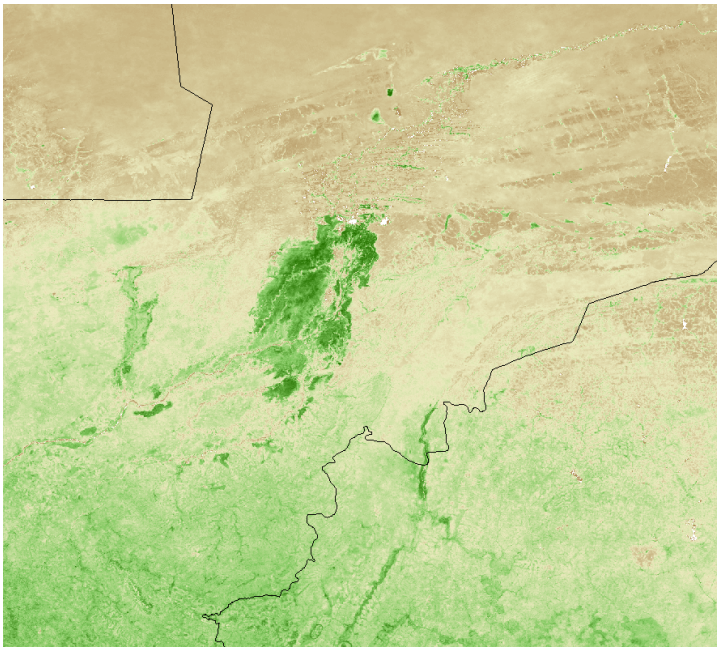
Results show a correlation between the location of the delta and the amount of seasons hurt by poor vegetation. Although the southern half of the delta saw minor changes, the northern half of the delta was plagued by 2-4 seasons of lost vegetation and agriculture. This is supported by the fact that the area surrounding the northern delta is consumed by dry grasslands and barren land. This indicates that three vital crops (rice, millet and sorghum) have seen decreased productivity from 2006 to 2011 as their locations have been overlaid with a high number of seasons affected. Livestock are also prominent in this area, supplying alternative food supplies when crops are not available, yet with a high number of seasons affected, there may not be enough open vegetation for livestock to feed on. While it is difficult to say the what exactly caused these seasons to be affected it is clear which areas are affected most often. This is valuable information as it reveals which food sources are most susceptible to changes in availability.

The next set of NDVI's show the aftermath of significant agriculture and vegetation losses from 2010 to 2011. 2011 was chosen as the Sahel saw its worst drought in years due to below normal rain levels, placing over 15 million people at risk. This drought resulted in widespread population movements of environmental refugees, increased violence and an inability to provide appropriate amounts of food to the most vulnerable. Provided by the USGS Famine Early Warning Systems Network, these NDVI's show a lack of stability in Mali's agricultural productivity. To show the difference between 2010 and 2011, we subtracted the bands of the two images to obtain a NDVI difference of the previous year. Green indicates healthy and abundant vegetation while brown indicates sparse and unhealthy vegetation. While this vegetation is not directly related to crops, it is a clear indicator of the amount of vegetation lost due to the crisis.

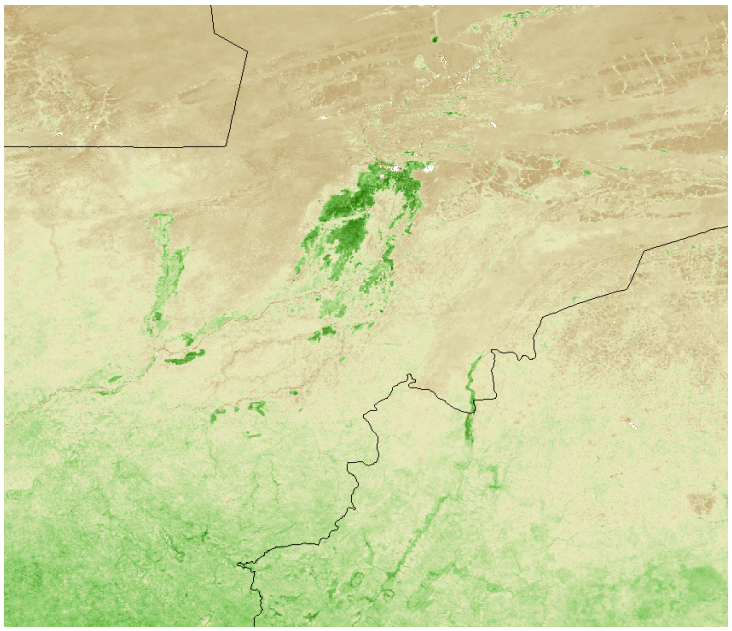
By visualizing vegetation health over large areas analysts can identify areas with significant declines in vegetation health and narrow down their study area. Mali saw significant declines in vegetation health near the Inner Niger Delta where farming conditions should be ideal and by narrowing in on this area we were able to apply additional methods to explore the possible causes and effects of this phenomenon.

[21] "Sahel Food Crisis." *Sahel Food Crisis*. N.p., n.d. Web. 03 May 2016. <http://sahelresponse.org/>.

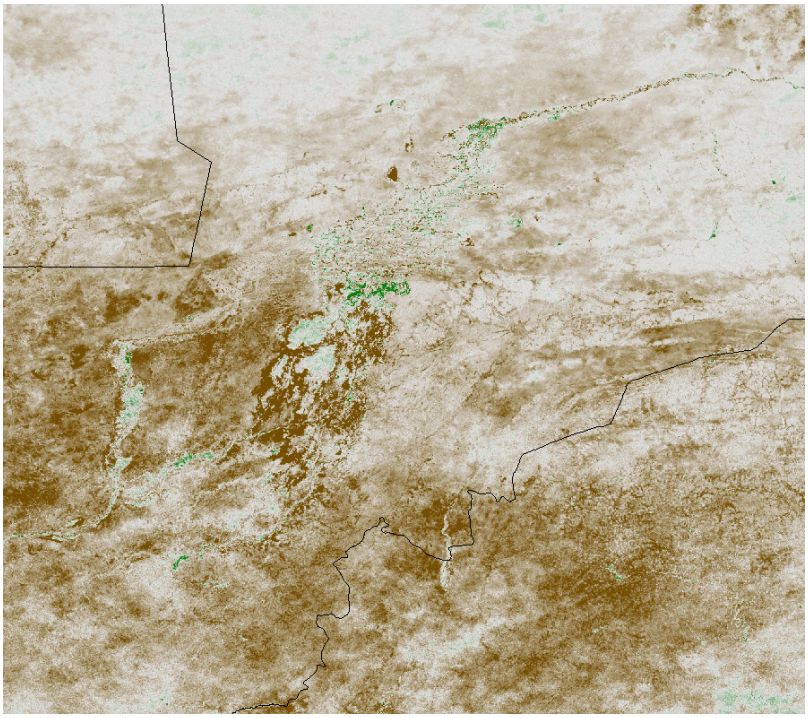
Once an area is determined to have unhealthy vegetation an analyst can then perform further analysis on the population and specific vegetation grown to determine if a food security crisis exists or whether the vegetation decline is benign.



NDVI November 2010



NDVI November 2011



NDVI November Difference, 2011

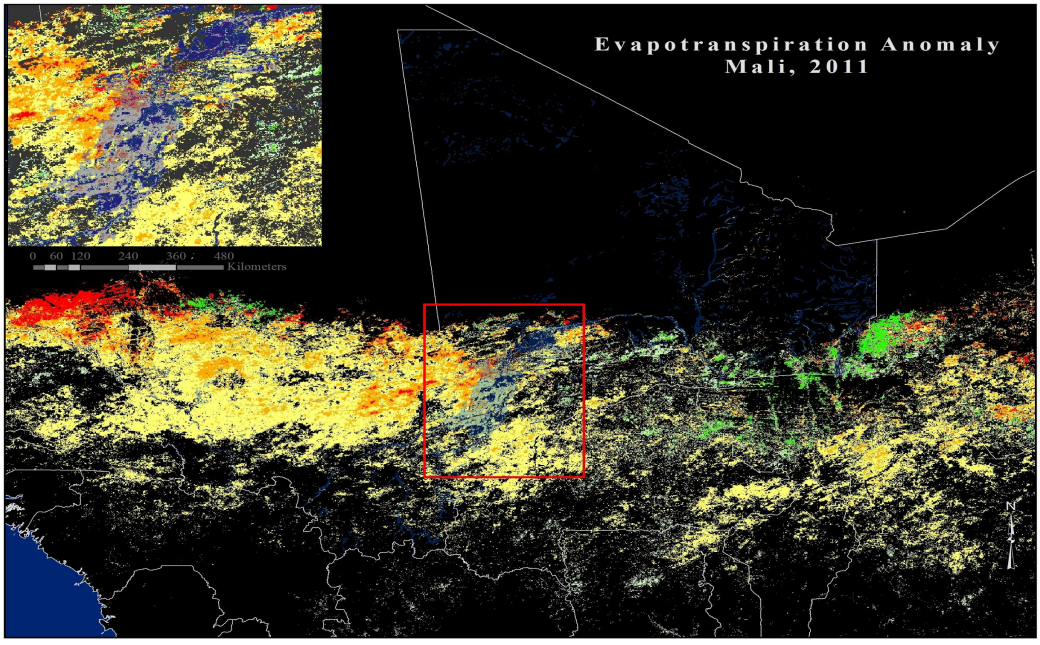
Maps 3: November was chosen as the constant as the end of the rainy season ends late october. Results here show that in 2010, vegetation was abundant surrounding the Inner Niger Delta, leading to a healthy growing season. However droughts in 2011 significantly reduced the amount of growing vegetation and crop production, as seen in the loss of green density. This difference is shown in the 2011 NDVI Difference, in which the 2011 NDVI was subtracted from the 2010. The data came from the Famine Early Warning System Network by USGS. FEWS NET provides additional value to our references as it is a leading provider of large scale open source environmental data.[22]

[22] "EMODIS NDVI (Normalized Difference Vegetation Index)." Products | Early Warning and Environmental Monitoring Program. USGS, Famine Early Warning Systems Network, 02 July 2013. Web. <http://earlywarning.usgs.gov/fews/product/115>.

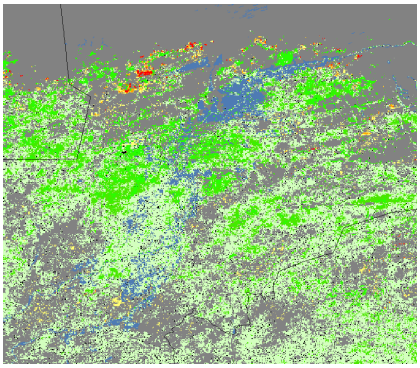
Evapotranspiration

The next method that was performed involved analyzing Evapotranspiration (ET) levels in 2011. Again, 2011 data was used as this is considered the least productive year due to lack of rain, extreme drought conditions and low flood levels. Data and analysis from this year can be applied to future events resulting from climate change to further understand the effects of a changing climate on food security. After measurements are collected, We concluded that areas showing significant changes in water absorption, which come directly from lower evaporation and transpiration levels, be identified in a food security crisis. A common way of identifying changes in water intake over time is to perform Evapotranspiration Analies (ETa's), showing changes in measurements from the previous year.

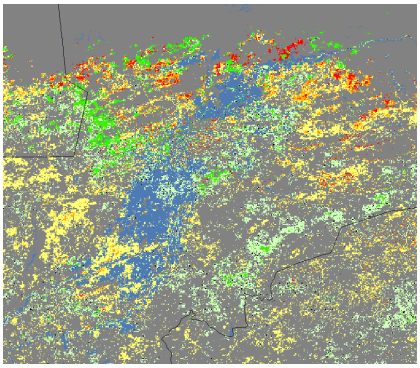
We collected ETa's from the USGS Famine Early Warning System Network ranging from 2003 to 2015, in addition to the Sahel Food Crisis Program. This data was more useful than vegetation indices as it will look farther into why certain crops are healthier than others. By analyzing plant and soil moisture from ET levels, analysts can have a better understanding of how much water is needed to satisfy vegetation and crops. Shown below is the results for the ET anomaly for 2011.



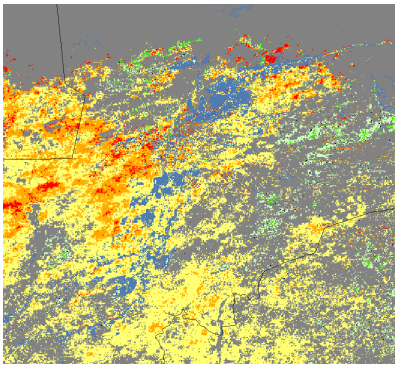
Map 4: This data is provided by Famine Early Warning Systems Network, a leading provider of open GIS data to large study. Results showed a significant amount of water lost in vegetation near the Inner Niger Delta from 2010-2011.



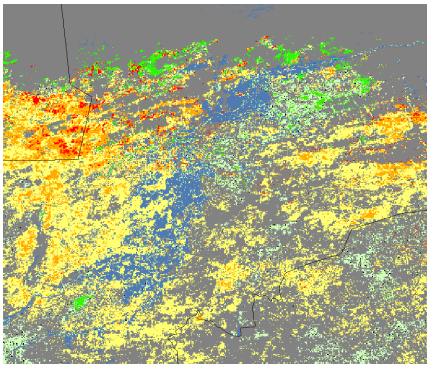
November, 2003



November, 2005



November, 2011



November, 2014

Maps 5: Over the course of 11 years, ETa levels have continued to decrease in the Inner Niger Delta as shown in the images below. In 2003, healthy ETA levels were accounted for due to high amounts of rain during the rainy season. With higher rain levels, more water was absorbed, evaporated and transpired. However 2005, 2011 and 2014 saw a continual decrease in water absorption due to diminishing rain levels, accounting for lower ETa results. This data is provided by Famine Early Warning Systems Network, a leading provider of open GIS data to large study. [23]

Results of our remotely sensed images show that 2011 lost a significant amount of water in plants and soils. Lower Et levels here are associated with lower rain levels/floods, diminishing water availability-absorption and thus lower evaporation-transpiration. This is directly correlated with the NDVI difference from 2010 - 2011; it is a perfect explanation of why such significant amounts of vegetation was lost the same year of abnormally low Eta levels. With lower rain levels and floods, vegetation and agriculture was unable to take in water and grow, resulting in catastrophic levels of vegetation loss and spiking low evaporation and transpiration levels. The four images above dive deeper into the problem, showing the gradual eleven year progression of lowering Eta records. This is a serious concern as this

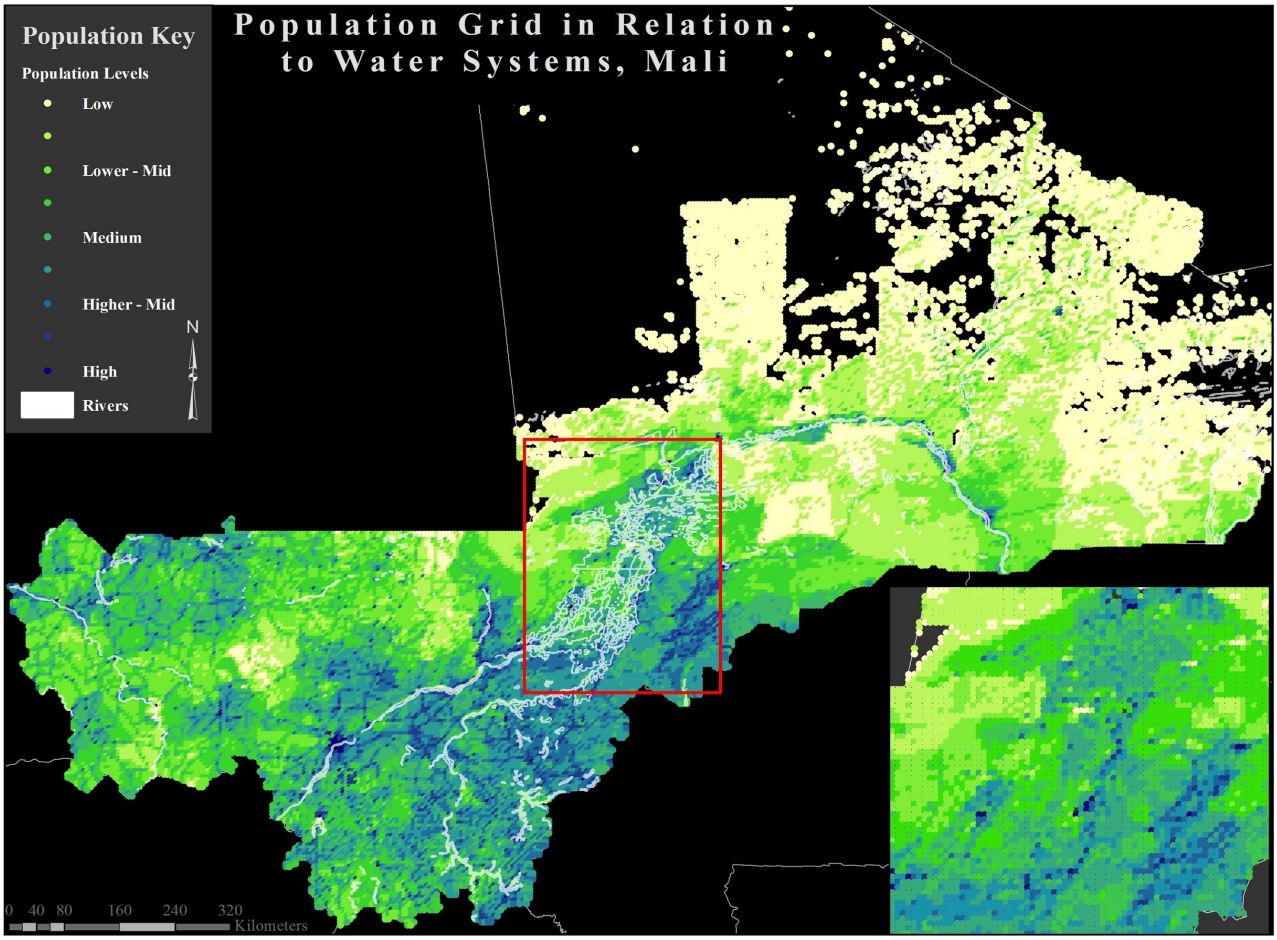
[23] "Seasonal Evapotranspiration (ETa) Anomaly - Jun-Oct." Products | Early Warning and Environmental Monitoring Program. USGS, Famine Early Warning Systems Network, Mar. 2014. Web. 11 Apr. 2016. <http://earlywarning.usgs.gov/fews/product/67>.

data suggests that Et levels will continue to decrease during the month of November. Given that November is considered one of the most agriculturally productive months, current and future food insecurity is without question. The inability to provide enough water to keep crops alive is a prime indicator that the Inner Niger Delta is currently and will likely remain a food insecurity hotspot.

Much like an NDVI, Evapotranspiration can indicate the health of vegetation and by using this method with NDVI results, analysts can monitor the vegetation health over a large area to target specific areas for further analysis. Evapotranspiration and NDVI results allow one to hone in on an area but to identify if food insecurity exists, an analyst must identify whether a population is reliant on the vegetation for agriculture.

Population Dynamics

The population grid below visualizes Mali's population distribution, clearly showing the majority living in the southern portion near urban centers and bodies of water. A population map such as this is a very useful tool for making connections between variables and visualizing trends. Using this indicator in conjunction with other data and visualizations allowed us to make inferences and conduct analysis on how population distribution plays a role in food security.



Map 6: This is a population grid that shows the Inner Niger Delta in relation to where the population lives. Results showed that a significant amount of people live around and are dependent on this area, as shown in dark blue. This data was obtained from DIVA GIS, a free geographic analysis program that offers general GIS data for selected countries. [24]

When analysts locate an area with significant declines in vegetation health and wish to investigate the possibility of food insecurity population mapping becomes crucial. In developing countries, like Mali, farming supplies sustenance for nearby populations as food does not move as far as it does in developed

[24] Download Data by Country, Mali." Download Data by Country. DIVA - GIS, n.d. Web. 11 Apr. 2016. <http://www.diva-gis.org/gdata>.

countries like the US. Thus, by identifying a population that is in close proximity to areas of declining vegetation health, as we have done for The Inner Niger Delta, analysts can reveal populations with possible food insecurity. However, a land cover classification is necessary to confirm the existence of a food security crisis.

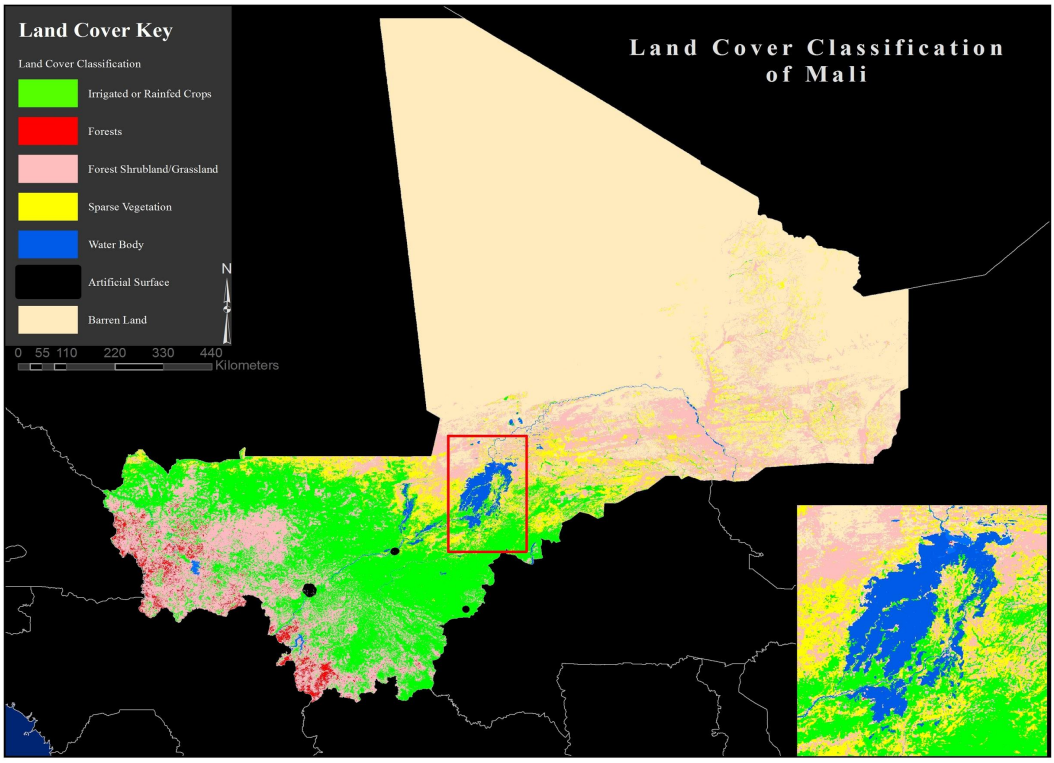
Land Cover Land Use Classification

A land cover-land use classification was done to determine the specific land cover types surrounding the Inner Niger Delta. Land cover is extremely important for resource assessment and decision making as it provides an understanding of what areas are utilizing and managing resources and land area effectively. Provided by the Food and Agriculture Organization of the United Nations[25], this data was derived from a raster based Globcover archive. Globcover is one of the most recent high resolution datasets in global land cover; and has historically been used in research and academia. Our analysis indicated that potentially productive land cover being underutilized or mismanaged should be identified when undergoing a Land Use - Land Cover Classification. By identifying the areas of transition between healthy vegetated areas and barren land analysts can identify areas known as “sparse vegetation”.These areas, if found close to sources of water or other agriculturally productive areas, may indicate improper management and utilization of land.

After performing our land cover classification, results indicated a significant amount of sparse vegetation surrounding the Inner Niger Delta, followed by equal amounts of irrigated and rainfed cropland. This came to a surprise, as it was expected that a majority of the area around the Delta would be surrounded by stable cropland, considering that this is one of the most agriculturally productive areas. This is a serious food security concern as the delta is not utilizing its full potential due to lowering flood levels, later productive seasons and droughts. When compared to the livelihood classification, all high water requirement crops are overlaid with sparsely vegetated areas. Sparsely vegetated areas indicate that there is not a stable source of water available. Our results show that the delta's most important and dependent crops are located within these areas of unreliable flood levels. It is clear that the most water dependent crops surrounding the delta are not managed properly as they are located in areas not classified as rainfed or irrigated cropland.

[25] "Land Cover of Mali - Globcover Regional Map." Food and Agriculture Organization of the United Nations, 04 June 2015. Web. <http://ref.data.fao.org/map?entryId=fd5b0dbc-4763-49a6-b141-5b26f5fe20c6&tab=metadata>.

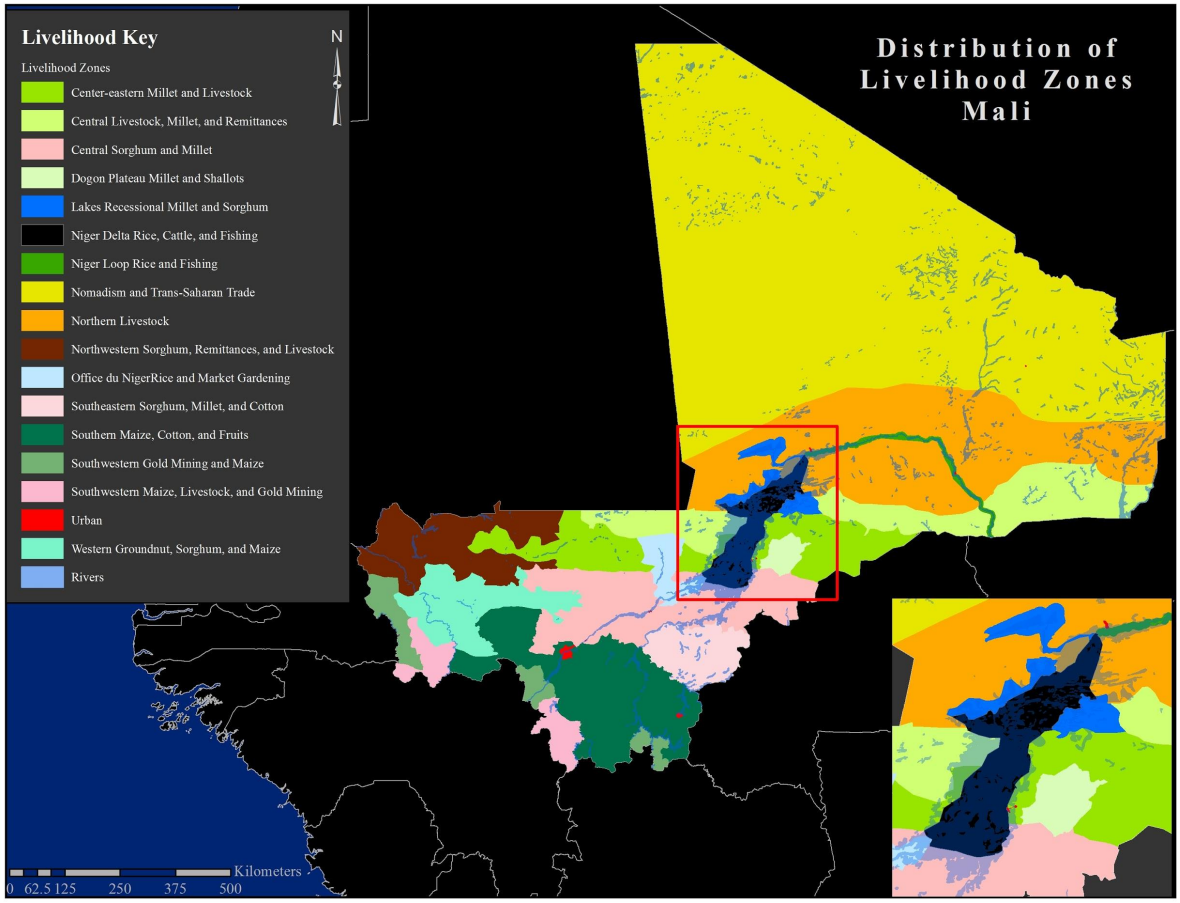
Our land cover classification also revealed that the vegetation, which has seen declines in health, is indeed used for agricultural practices. This is an important distinction as the health of a forest may not have direct effects on the availability of food. By identifying areas of declining vegetation health, locating a population which is in close proximity to that vegetation, and confirming that the vegetation is used agriculturally an analysts can, as we have done here, identify areas of possible food insecurity and confirm the existence of that insecurity. To more fully understand degree of crisis in a specific area, an analyst can then identify other factors that contribute to the situation, such as conflict or infrastructure, and explore the deeper relationships between variables.



Map 7: This is Land Cover - Land Use Classification. Results showed a significant amount of sparsely vegetated, non productive land cover surrounding the Inner Niger Delta, showing an inability to manage and utilize land cover efficiently. This was provided by Food and Agriculture Organization, a leader in providing assessments and data to global food security and stability.

Livelihood Classification

To get a general sense of the distribution of food in Mali, we obtained livelihood zone classification data from the Famine Early Warning Systems Network[26], a leading provider of early warnings and analysis of food insecurity. A livelihood zone is an area of common life patterns, including options for food and market opportunities. Classifying each area into the most dominant food source, a livelihood classification allows analysts to monitor food security within specific areas. This was important to understand in Mali as it provides a general geographic orientation of food sources and allows for understanding of how each area of Mali survives.



Map 8: A livelihood classification classifies the various food sources most available in an area. Results showed a significant amount of water dependent/seasonally vulnerable food crops located around the Inner Niger Delta. Data was provided by the Famine Early Warning System Network.

Our analysis found that the most revealing indicator from a Livelihood classification is the current food sources that are under threat from disruptive forces. Disruptive forces is used broadly to include climatic

[26] "Mali Livelihood Zones 2014." USGS, Famine Early Warning Systems Network, n.d. Web. 11 Apr. 2016. <http://www.fews.net/west-africa/mali/livelihood-zone-map/march-2015>.

forces such as drought, flooding, as well as human disruptions such as conflict. These disruptions, depending on the livelihood type as well as the degree of disruption, can cause damage to crops or the people and facilities needed to manage them. Identifying these disruptions, using other methods or reported information, and overlaying their locations on a livelihood classification will reveal which crops or livelihoods are under threat allowing analysts to understand which food sources are available or unavailable at a given time.

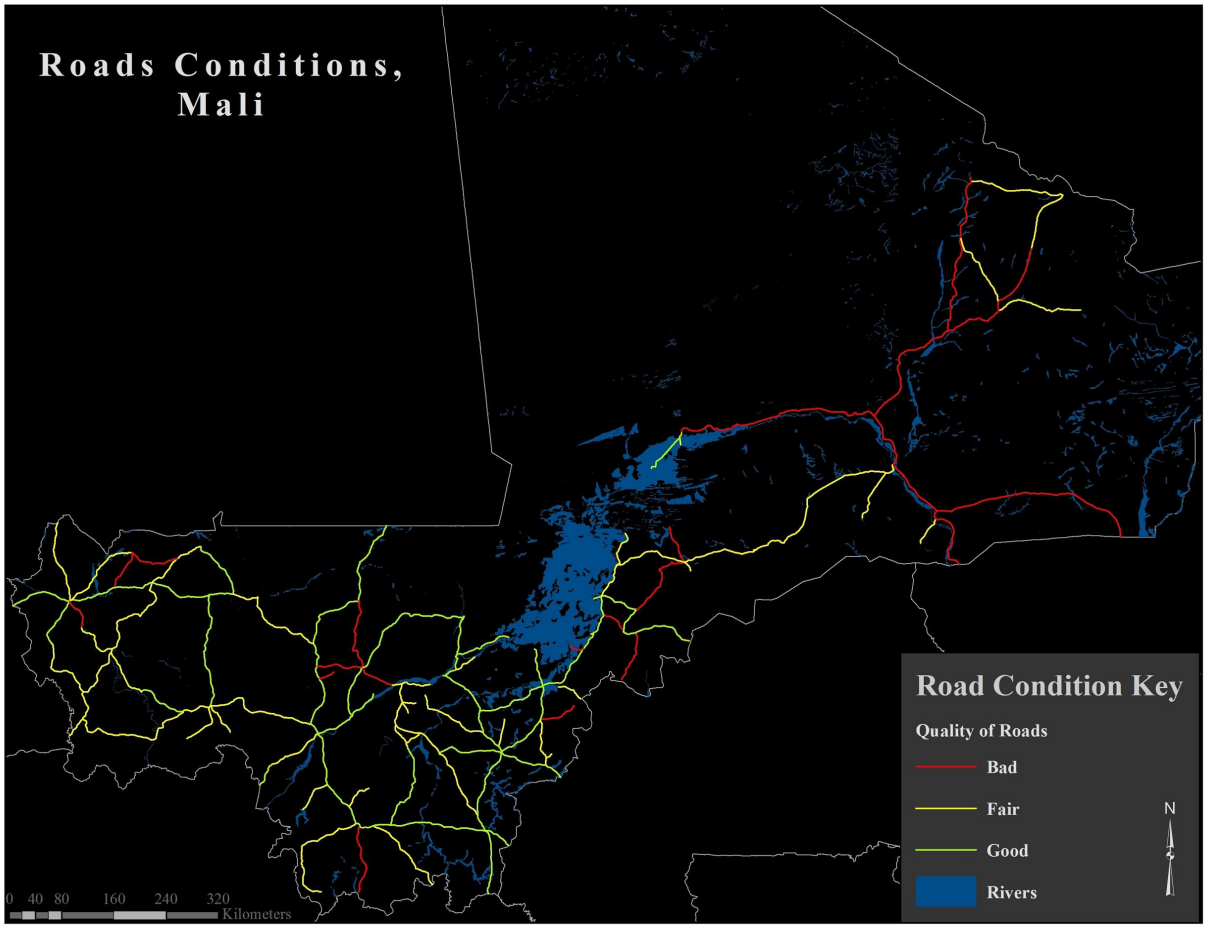
Our results indicated that livestock, rice, fishing, millet/shallots and sorghum are the dominant crops in the area. Livestock, rice, and fishing are all highly dependent on sources of constant water, making them extremely vulnerable to drought and climate change. With lower water levels associated with increased international usage and dam construction upstream, four of the most dominant crops in Mali are in serious danger. Although millet, shallots and sorghum are more adaptable to drier conditions, they are dependent on constant irrigation which takes up significant amounts of water. Overall, the dominant food sources surrounding the delta have high water requirement levels, making them all extremely vulnerable to both climatic and demographic changes.

Infrastructure Analysis

The next factor that was used analyzed was infrastructure. The poor, unstable and disconnected country of Mali simply does not have the money nor the resources for high quality infrastructure in a land cursed by desert conditions. When looking at the root causes of this inability, one must take a look into other social aspects to the issue. In this section will be analyzing conflict in relationship to infrastructure to get help understand this connection between infrastructure and food insecurity.

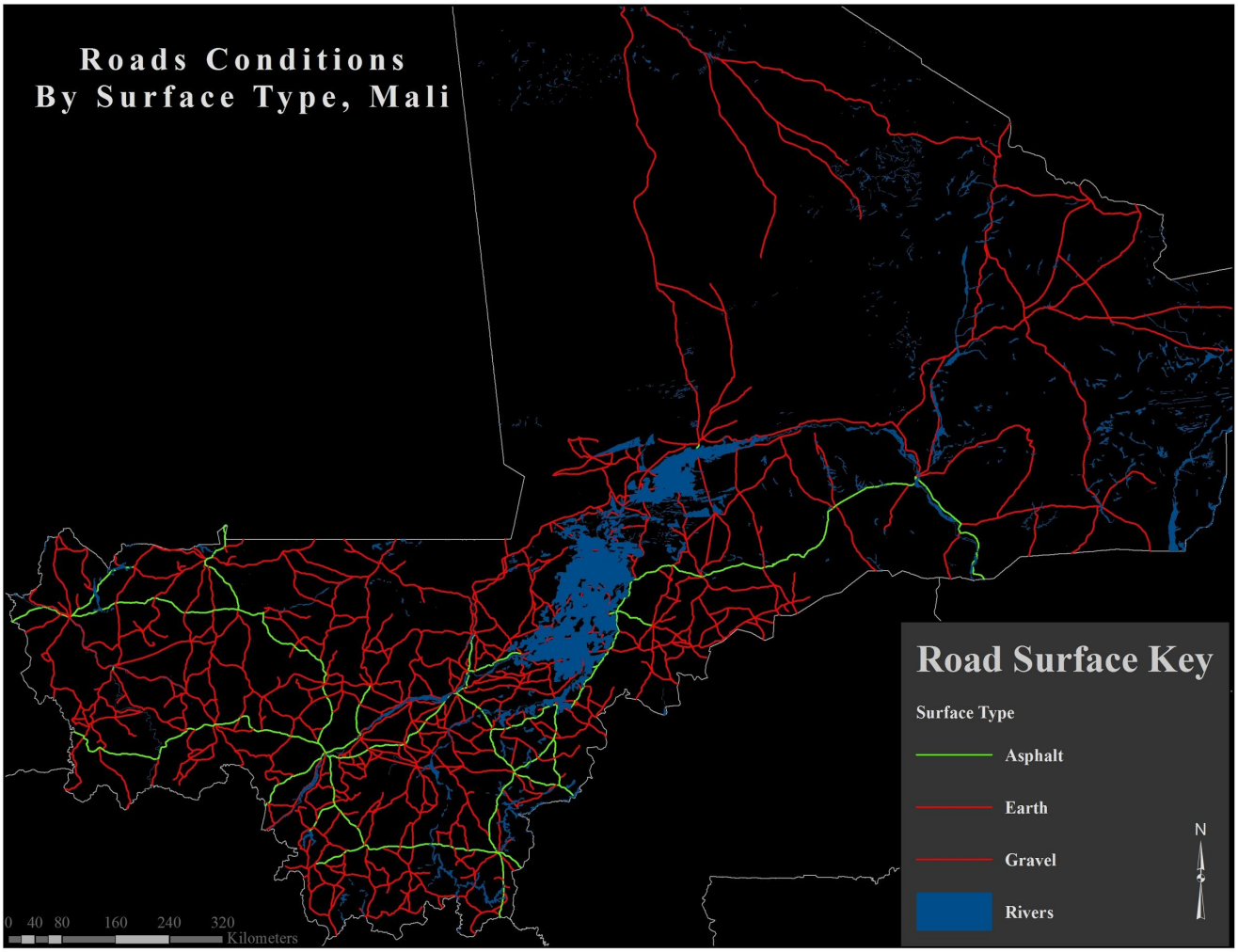
Adequate road conditions are needed to allow for the efficient transportation and trade of agricultural goods. To look further into this, road condition data was collected from the African Development Bank Group, an institution designed to aid in the development of economic and social services[27]. Classified by three different conditions - good (green), fair (yellow) and poor (red), the viewer has a good a sense of the quality of roads and the efficiency of transportation routes.

[27] "Mali Livelihood Zones 2014." USGS, Famine Early Warning Systems Network, n.d. Web. 11 Apr. 2016. <http://www.fews.net/west-africa/mali/livelihood-zone-map/march-2015>.



Map 9: These roads are classified based on the quality of the surface. This is important to analyze when assessing effective distribution of food sources. Results showed only one classified "good" major road that spans the entire length of the Delta. This data was provided by African Bank Development Group.

Results showed that although the southern half of Mali had generally higher quality roads, the road system near the Inner Niger Delta tended be in fair or poor condition. The same dataset was divided into surface types - asphalt, dirt and gravel. Asphalt was assumed to be in higher quality than the other two, thus the color green was assigned to this surface type. Dirt and Gravel with both assigned to red as the quality of the road will naturally be limited.



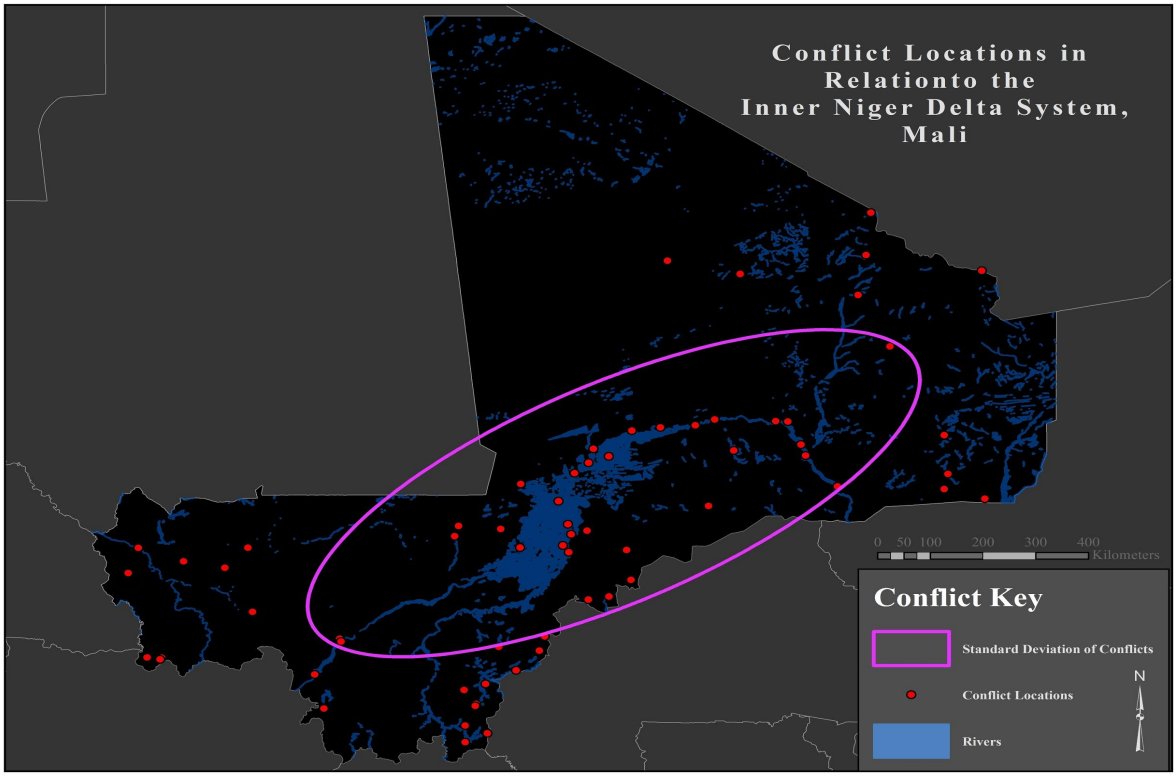
Map 10: Road conditions based on surface type. Results showed that there is only only one asphalt road spanning the length of the delta. Data is provided by the African Bank Development Group.

Results showed that the Inner Niger Delta only has one major asphalt road located down the entire length of the delta. Both of these results are shocking as the delta is considered one of the most agriculturally productive areas in West Africa, with millions of people migrating here to take use of this vital system. Distribution of food in this agriculturally productive area is thus limited, restricting the distribution of food exports to food insecure areas, the agricultural inputs needed to keep farms sustainable and productive and the ability to be cost-effective in collecting/transporting food.

With the onset of an increasing population and dependence on the delta to provide the proper nutrition to those in need, there is a concern for the continued degradation of Mali's road system. If farmers want to

produce enough food for this growing population, quality infrastructure needs to be in place to to connect farms with sources of agricultural input and local/regional markers, linking them to sources of productivity, giving them a chance to survive. Better infrastructure around the Delta would also directly benefit general business, providing an opportunity for Mali to invest in more sustainable agriculture which may lead to higher yields and more fruitful production. Overall, food security in the Inner Niger Delta could greatly be reduced with more efficient and higher quality roads.

Conflict

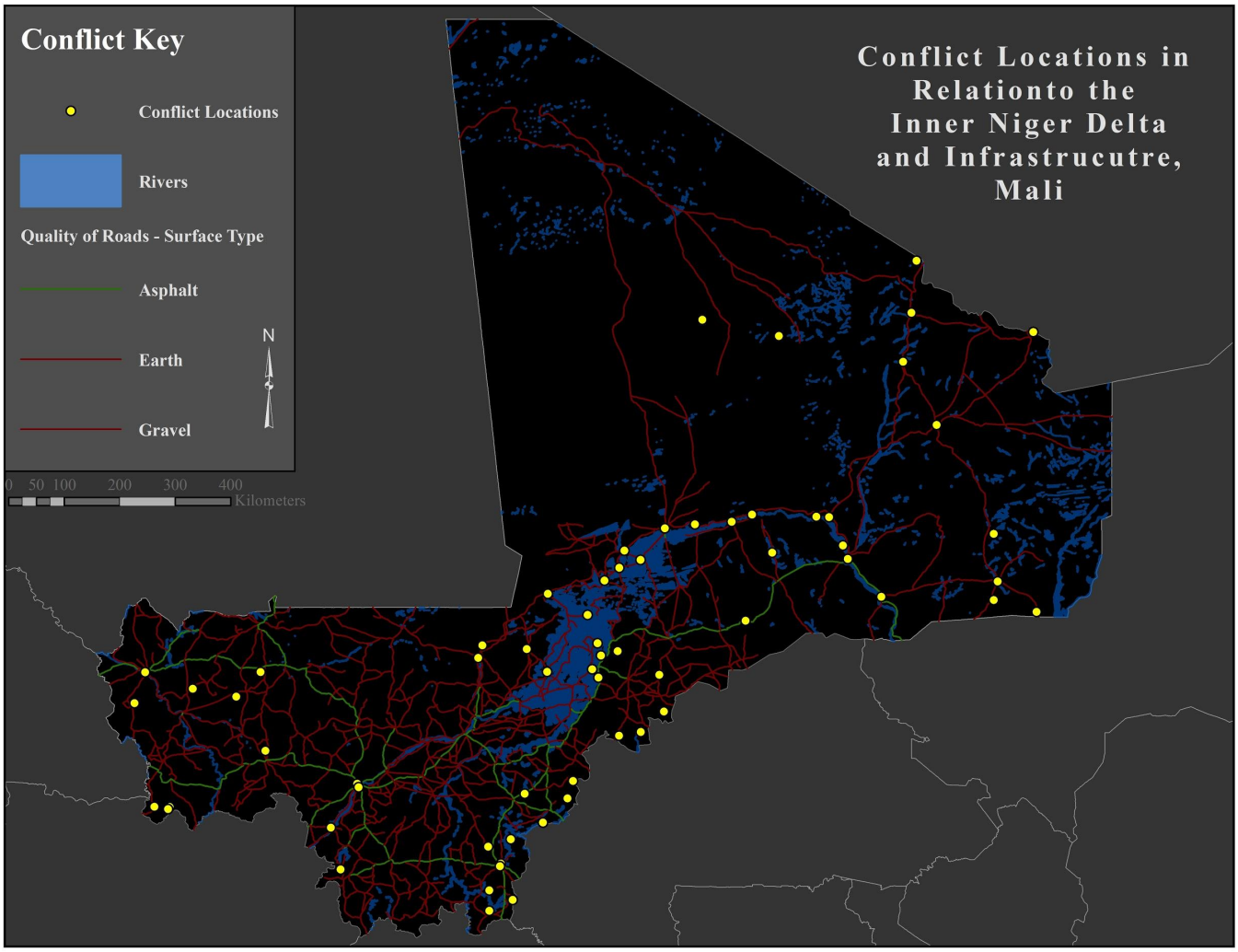


Map 11: This visualization shows the standard deviation of conflicts in the Inner Niger Delta. Results clearly show that the delta is prime location for and violence, a serious concern given that large amount of food are produced in this area. This data was provided by Open Source ArcGIS data.

As mentioned before conflict in Mali has been exacerbated in several ways but the main force driving conflict today comes from heavily armed Islamic fundamentalists seeking control. More organized conflicts persist in the mid to northern sections; however, sporadic terrorist attacks and conflicts occur in southern regions including the Capital of Bamako and urban centers located along the Niger River. These conflicts, especially those occurring in southern regions, can have very adverse effects on food security in Mali as the situation is already very fragile. Attacks on key agriculture production, storage, or transportation areas can hinder the availability of food or drive prices up reducing people's access. The conflict map shown here resulted in a clear relationship between conflict sites and areas of high agricultural production. By running a standard deviation algorithm on the conflict sites we can visualize

areas where the majority of attacks take place. This data was provided by Open Data ArcGIS[28]. ArcGIS is the premier geospatial software and offers a wide range of data available for users.

A second conflict map helps add geographic reference by including roads, and once again conflicts seem to correlate with urban centers, agricultural productivity and water.



Map 12: This map simply combines conflict locations with road conditions to see where poorly constructed roads could be potentially be cut off due to conflict. Results showed that many poor quality roads expanding from the delta see conflict, indicating that they are prone to road closures. This is a great example of how food distribution and allocation can be altered due to conflict and violence.

[28] "Mali Tuareg Bambara Conflict." ArcGIS Open Data and NGA Public, n.d. Web. <http://opendata.arcgis.com/datasets/8ab1ead79c79403abad2a081917190cb_2>.

These results are very concerning as most of the attacks are located directly in the Inner Niger Delta agriculture zone. In addition, when compared to the surface quality of the major road systems in Mali, the location of these attacks on the poorly constructed earth and gravel roads located within close proximity to food sources is disturbing. These roads are in highly insecure as they are naturally unable to distribute food efficiently. When combined with the fact that high amounts of conflict occur at these locations, these roads will likely be destroyed or cut-off from other main roads due to conflict aftermath from bombings, fires and other terrorist activities. With only one main asphalt road stretching the entire delta and a major conflict hotspot in the center, there is an additional concern that the only efficient road system may be highly vulnerable to road closures and damage from attacks.

Conclusion

US foreign policy goals in Sub-Saharan Africa include good governance, peace, stability, and sustained economic growth. However food insecurity persists, negatively affecting all of these goals. Without a sustainable and reliable source of food Mali, and other West African countries, continue to suffer. This is a multi-dimensional problem, continuously affecting all aspects of life. Many of the issues in this region stem from food insecurity as without the basic necessities conflict naturally ensues, further deteriorating the situation from all angles.

Before we begin solving the issues associated with food insecurity, effective methods of targeting, analyzing, and predicting food insecurity must be developed and tested. We have begun that process here by analyzing different methods and indicators. We have developed a set of macro and micro methods which reveal specific indicators and allow analysts to accurately and efficiently identify food insecure areas and assess the degree of crisis.

By utilizing the macro level methods of NDVI's, evapotranspiration levels, population maps, and land cover classifications analysts can broadly search large areas for indicators of food insecurity and systematically narrow their study area to specific locations. Once these macro level analyses have been completed, analysts can begin to apply micro level methods which allow for in-depth analysis. Micro level methods include, but are not limited to, analysis of conflicts, infrastructure, and livelihood zones. Micro level assessments give insight into the inner workings of a food security crisis such as its causes and effects.

In order to test our macro level methods we applied them to the West African region and attempted to target a specific region of food insecurity. We applied a NDVI as well as evapotranspiration levels to the region and identified an area of Mauritania, bordering Senegal, which displayed significant declines in vegetation health. We then obtained population data and found that much of the country's population lives in the area with declining vegetation health, indicating a strong potential for food insecurity. However, to confirm a crisis we had to apply our last macro level method, a land cover classification; this revealed that the vegetation, whose health was in decline, was in fact being used for agricultural. This test revealed that our methods and indicators could be successfully used to identify areas of food insecurity, even at the

regional scale. We did not apply our micro level indicators to this area due to time constraints but we are confident in their ability to reveal useful information.

What makes these indicators extremely useful is their ability to be applied outside of West Africa. These indicators have intentionally been developed to assess multi-faceted issues regarding food security, having inherent flexibility in their application. Given that they are adaptable, these indicators can be used to assess food security at any spatial location given the steps we propose. Additionally, due to our indicators multi-dimensional nature, their application to food security raise critical insights to other dimensions of interest. By using these methods, social, political, economic and environmental assessments are naturally given. This means that our methods development can be used to assess a wide range of other factors other than food security including population movements, environmental refugees, conflict, violence and economic collapse. The inherent flexibility in our indicators thus adds extra value to our methods development.

We have a moderately high level of confidence in our indicators ability to accurately identify and assess areas of food insecurity in West Africa. We tested our methods and indicators for accuracy and successfully located an area of food insecurity. However, due to time constraints as well as technical knowledge constraints associated with remote sensing techniques and the complexities associated with such a multi-faceted problem we feel that we have merely scratched the surface of what can be done to analyze food security.

Technical Terms and Definitions

ArcGIS - A Geographic Information System software package that allows users to view and manipulate spatial data in a user friendly environment.

Climate Change - term for the observed changes in the raising of the earth's temperature and the ensuing effects on our environment.

Evapotranspiration (ET) - sum of evaporation and plant transpiration of photosynthetic organisms. Evaporation is the conversion of a liquid to gas and is a great indicator of surface water moisture of soils, canopies and waterbodies. Plant transpiration is the evaporation of this water from plant leaves, stems and flowers.

Evapotranspiration Anomaly (ETa) - Differences in water absorption measurements in vegetation from the previous year.

Geospatial Indicator/Marker/Signature - Method of identifying trends, scenarios and crises through GIS, remote sensing and imagery analysis.

Geographic Information Systems (GIS) - process of displaying, collecting and analyzing spatial data (both manmade and natural) from aerial or satellite collection.

Image Classification - extracting valuable information from a remotely sensed image and classifying it into common groups.

Land Cover Classification - type of image classification that classifies and differentiates the physical surfaces of the earth (e.g, barren land, agriculture, dessert, open water, development etc.)

Livelihood Classification - classifies spatial data based on current food sources. Helps to determine how people survive and what sources of food they are most reliant on.

MODIS - Moderate Resolution Imaging Spectroradiometer: scientific instrument placed on satellites. Provides large swath with imagery based on 36 spectral bands.

NDVI (Normalized Difference Vegetation Index) - one of the most commonly used method of measuring plant health, abundance and diversity. Measure plant output of photosynthetic activity and greenness.

Remote Sensing - the process of acquiring data of the earth's surface, both manmade and natural, by satellite or high-flying aircraft.

Remote Sensing Index - The manipulation of the pixels in a remotely sensed image to tailor a user's variable of interest or study.

Ramsar List : Wetlands of International Importance - identifies wetlands that have a vital significance to ecological, cultural, scientific and recreational systems and services. Adopted in 1971, these wetlands are protected by the national government under the Ramsar Convention.