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Mosquito-Borne Illnesses and their Disproportionate Impact on Variant Infrastructures: A GIS Map Comparison of Three Regions.

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ABSTRACT

Mosquito-borne Illnesses and their Disproportionate Impact on Variant Infrastructure: A GIS Map Comparison of Three Regions.

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Mosquitoes are the deadliest animals on earth and they spread diseases through their bites. Chikungunya, Dengue, Malaria, Yellow Fever, West Nile Virus, and Zika are six diseases of concern that are transmitted by mosquitoes. This honors thesis will attempt to provide relevant information and a critical analysis of current literature. Disease descriptions of the aforementioned illnesses and country evaluations for Niger, South Sudan, and the United States of America are included for comparison and evaluation. A Geographic Information System was used to create several maps comparing the three regions of the earth specified. The models are used to show country data in a visual way that is instantly intuitive to understand. Combining literature reviews, world data, and maps of mosquito-borne diseases and regional world-standings, this thesis indicates macro- and micro- level risk factors that influence the rate of disease spread, morbidity and mortality rates, and incidence and prevalence of the viral and parasitic infections found around the world. Education and infrastructure were two upstream risk factors indicative of endemic areas of mosquito-borne diseases. Figures and tables have been included to condense information and provide easy analysis and comparison of preventative measures or country information.

Keywords and phrases: disease, education, infrastructure, mosquito, mosquito-borne, Niger, risk factors, prevention, South Sudan, United States.

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Introduction

The World Health Organization recognizes six mosquito-borne illnesses as neglected tropical diseases. They are: Chikungunya, Dengue, Malaria, West Nile Virus, Yellow Fever, and Zika. The organisms that cause these diseases present their own unique and significant abilities to devastate a population. Modern preventative measures for mosquito-borne diseases have been in place for years: The Bill and Melinda Gates Foundation works with partners to help accelerate the eradication of Malaria, and local grass-root programs are teaching communities how to prevent mosquitoes from reproducing in backyard containers full of water, and many others. But the major problem posed by intervention practices is funding and access to information. For example, higher education levels are shown to correspond to increased use in insecticide treated nets within a home (Nyahoga & Bochkaeva, 2018; Kanmiki, Awoonor-Williams, Phillips, Achana, Akazili, & Bawah, 2019). Without sufficient education, individuals may not understand the importance of keeping the net sealed throughout the night—especially when sleeping conditions could be improved by propping the net open for a nice breeze.

On an individual basis, sickness caused by mosquitoes can prevent an employee from going in to work, a farmer from tending to their fields, or a mother from collecting water for her family. On a local level, less time at work means that there is less money in the family to be spent on basic human needs such as food and medicine at the small store in town which then contributes to poorer community economic output and subsequent systemic effects that impact health and well-being (Rodrigues, 2017; Zellweger, Cano, Mangeas, Taglioni, Mercier, Despinoy, & Teurlai, 2017).

To emphasize the systemic effect of mosquito-borne diseases, it has been shown that morbidity (actively being diseased or disabled) and mortality (death) associated with these endemic diseases often stalls or negatively impacts communities and even nations from successfully competing in the global economy (Sen, 1998). Lack of goods stemming from an ailing or diminished workforce exacerbates the ability of a nation to grow economically and thus creates a negative feedback loop directly affecting the quality of life for residents of these areas (Reutlinger, 1986). It is well documented that a poor economy leads to poor infrastructure (Pinstrup-Anderson & Shimokawa, 2007; Bausch & Schwarz, 2014; Limao & Venables, 2001). When roads remain in disrepair, transportation is limited (Banerjee, Duflo, & Qian, 2012), which can lead to improper waste disposal when there is not an easy way to relocate trash; this can cause disease vectors such as mosquitoes to accumulate in the area (Selendy, 2011). Unclean drinking water can occur when runoff and groundwater become contaminated by the waste and can cause diarrheal diseases (Blum & Feachem, 1983). Overall, poor infrastructure can lead to fewer jobs due to the inability to remain in good health and the inability to commute to and from work, reinforcing the gap between the more affluent members of society and the impoverished masses (Ogun, 2010).

Morbidity and mortality numbers can indicate that mosquito-borne illnesses disproportionately affect poor infrastructure areas, leading to an increased risk of disease and death due to poor standards of living, economic deficits, and poverty. Therefore, the current study will investigate how and why mosquito borne illness are more rampant in some areas and not others. Figures constructed with relevant information will provide focus on the research that has already been conducted for these six neglected tropical diseases, what has allowed their numbers to burgeon throughout history, and the ways in which they are being combated or could be overcome in the future. This will be accomplished through a comparison analysis of two regions in endemic Sub-Saharan Africa: Niger and South Sudan, and the developed region of the United States of America. This comparison will be accomplished through the creation of geographic information system (GIS) mapping of comparison regions to include layers of risk factors and current interventions. A cartographic model using GIS software will be created to show overlapping risk factors specific to each area and how the proliferation of diseases in poor infrastructure areas compare to more affluent communities.

Background

Malaria is the leading cause of mortality in children under five years of age in Sub-Saharan Africa (Chukwuocha, Okpanma, Nwakwuo, & Dozie, 2014). The majority of these deaths are often centered around locations that are inundated with mosquito breeding grounds, poorly built structures, and limited education. Along with the high rates of mortality, morbidity rates in these areas should also be comparatively higher. Malaria, along with Chikugunya, Dengue, Yellow Fever, West Nile, and Zika, are plaguing the vulnerable populations of the world who are stuck in an epidemiological transition from a high burden of infectious disease to a higher burden of chronic disease, unfortunately resulting in what global health specialist deem areas with a double burden of disease, with high rates of infectious and chronic disease respectively (Kushitor & Boatemaa, 2018). However, efforts are in place to combat these diseases. The following section details the transmission of mosquito borne diseases, the key genera of mosquitoes that carry the six most threatening diseases, key risk factors, and the current global intervention response.

Pathophysiology of a Bite

Mosquito-borne diseases are spread in two ways: through urban or sylvatic cycles. The urban cycle of disease spread occurs when a mosquito transfers disease from one human to another, while sylvatic spread is from animal to human (Ganesan, Ben, & Reid, 2017). The urban cycle is predominant in areas with larger populations of humans that serve as blood-hosts for the mosquitoes. Sylvatic cycles occur when humans are living in relatively close quarters to species that can harbor zoonotic diseases transmissible by mosquito bite. Primates and avian vertebrates (e.g. birds) are examples of species that are integral to the sylvatic cycle. The female mosquitoes are the only sex that feed on blood because they require blood meals to develop their eggs. Because of this, mosquito-borne diseases are transmitted through female mosquitoes *only*.

Once the mosquito finds a host and begins to feed, it ingests the viruses or parasite that causes one of the six diseases being discussed. These organisms start to proliferate inside the mosquito's gut. The viruses and parasites travel from the mosquito's gut and up to their saliva glands. When the mosquito bites and injects their saliva to keep the host from recognizing that they are being fed on, the disease can then spread from the mosquito to the host. Each virus or parasite targets different cells and organs within the body, therefore they each present with different symptoms and risks.

Neglected Tropical Diseases

The World Health Organization (WHO) categorizes mosquito borne illness as vector-borne Neglected Tropical Diseases. Of the six most threatening of these vector diseases (Chikungunya, Dengue, Malaria, Yellow Fever, West Nile Virus, and Zika virus), three primary genera of mosquitoes proliferate them: *Aedes, Anopheles,* and *Culex*. Each mosquito genus can be found throughout the world in regions that can support their life cycle and breeding necessities.

The introduction of global travel through airlines, cruise ships, and public transportation has allowed the spread of mosquito-borne diseases. As infected people came into contact with mosquitoes of new areas, the insects were able to advance the spread of disease to new populations. As a result of human movement, these mosquito-borne diseases have become a global health concern.

Aedes Mosquito

The *Aedes* genus is responsible for the transmission of four of the six World Health Organization recognized Neglected Tropical Diseases spread by mosquitoes: Chikungunya, Dengue, Yellow Fever, and Zika. Species of *Aedes* mosquitoes can be characterized by their small black bodies, light and dark patterned scales on the abdomen and thorax, and alternating light and dark bands on their legs.

Chikungunya. Chikungunya virus was first diagnosed in a patient from southern Tanzania in 1952; the disease began to emerge as a global epidemic in the late 1990s and early 2000s when migrant populations from confined pockets of Asia and Africa dispersed across the world (Ganesan, Ben, & Reid, 2017).

As of September of 2019, 115 countries in Africa, the Americas, Asia, Europe, and nations in the Indian and Pacific oceans have reported cases of Chikungunya (Centers for Disease Control and Prevention). Chikungunya shares similar symptoms to Dengue and Zika, with one glaring difference: high fever and systemic joint pains known as polyarthralgia. This symptom is so severe that the name “chikungunya” comes from a Makonde phrase that means “that which bends up” or “to become contorted” -- illustrating the debilitating posture taken on by those infected (Yactayo, Staples, Millot, Cibrelus, & Ramon-Pardo, 2016). 50-97% of infected individuals present clinical symptoms that are indicative of having contracted the virus (Lum & Ng, 2015).

As of now, there is no cure for Chikungunya virus. Treatments include medications like antipyretics and NSAIDs (Rougeron, Sam, Caron, Nkoghe, Leroy, & Roques, 2015), but their efficacy has not been thoroughly evaluated (Thiberville, Moyen, Dupuis-Maguiraga, Nougairede, Gould, Roques, & de Lamballerie, 2013). More attention may be directed towards creating a cure now that Chikungunya has been found in more developed nations within the past six years.

Dengue. Dengue fever is caused by a virus that has four different serotypes of the disease: DENV-1 through DENV-4. It is possible for an individual to contract all four diseases at different points in time, mainly in hyperendemic areas where all serotypes are present. On average, Dengue fever infects nearly four hundred million worldwide (Sengupta 2019).

Dengue fever can present normally or be asymptomatic, but in the hyperendemic areas the virus can incur Dengue Hemorrhagic Fever or Dengue Shock Syndrome (Sengupta, 2019). Normal presentation of Dengue is a series of flu-like symptoms such as fever, joint aches and pains, rash, and vomiting. As with Chikungunya, there is no cure, but treatment for Dengue includes increased fluids to replenish what has been lost due to sweating and vomiting.

Yellow Fever. 2013 data from the World Health Organization estimates up to 170,000 cases of Yellow Fever each year, resulting in around 60,000 deaths. Three forms of Yellow Fever exist and are categorized as Sylvan, Intermediate, and Urban (Smith, 2019). Sylvan Yellow Fever is also known as Jungle Yellow Fever because it is primarily transmitted between forest monkeys. Intermediate Yellow Fever is found when humans live near a forest line and mosquitoes can transmit the virus from monkeys to humans or human to human. Urban Yellow Fever exists in more densely populated areas where humans are bitten by mosquitoes and the disease is transmitted in that way.

Yellow Fever can present in many ways, with some individuals not knowing that they were sick while another may die from the severity of their symptoms (Smith, 2019). Flu-like symptoms are common to most cases and liver damage can cause the namesake yellow skin and eyes. Severe cases can induce renal failure and hemorrhaging that may prove fatal.

While a vaccine is available to help prevent infection in those most at risk of acquiring Yellow Fever, there is no specific antiviral treatment once a person has become infected (Smith, 2019). Management of symptoms is the primary goal of improvement (Smith, 2019).

Zika Virus. Unlike the other diseases on this list, Zika can be transmitted in more ways than just by a mosquito bite: the virus is a communicable disease that can be passed from person to person (Schnee, 2018). Zika can be transmitted through unprotected sex with someone infected with the virus, even if they are not showing any symptoms (Schnee, 2018). A blood transfusion has also been found to spread Zika to the recipient (Schnee, 2018).

Most Zika cases do not exhibit any symptoms, while some can experience a mild fever, maculopapular rash, conjunctivitis, headache, and muscle or joint pain (Schnee, 2018). A rare, but serious, neurological condition linked to having a history of Zika has been reported (Schnee, 2018); Guillain-Barre syndrome is an autoimmune disorder that causes the immune system to attack the peripheral nervous system, causing damage to nerve cells (Schnee, 2018). Instances of microcephaly and other developmental or neurological problems were a result of Zika infections during pregnancy, although at what stage of pregnancy is the most damaging to a fetus has yet to be determined (Haug, Kieny, & Murgue, 2016).

Management of symptoms is the only course of action once a person becomes infected with Zika (Schnee, 2018). But, a DNA-based vaccine has been enrolled in clinical trials since 2017, and a vaccine using a live, attenuated version of the virus began clinical trials in late 2018 (Schnee, 2018).

Anopheles

The *Anopheles* genus of mosquitoes is perhaps the deadliest vector on Earth. Characterized by their angled resting position, this genus is responsible for transmitting the Malaria parasite.

Malaria. The *Plasmodium* parasite genus is the cause of all strains of Malaria in humans, primates, and birds (World Health Organization, 2019). The Malaria sporozoites are injected into a human from the saliva of an *Anopheles* mosquito and travel through the blood and into the liver (World Health Organization, 2019). The parasite spores feed off the liver and quickly multiply, spreading to red blood cells throughout the body (World Health Organization, 2019). The infestation of the red blood cells by the parasite is what causes the anemic symptoms associated with Malaria (World Health Organization, 2019). White blood cells attempt to remove the infected red cells, causing fluctuations in body temperature as the infection is being fought off (World Health Organization, 2019). In more serious cases, the infected red blood cells attach to tissues and capillaries, causing a decrease in free blood flow which produces more anemic affects (World Health Organization, 2019).

Quinine has historically been used to treat Malaria, but as the parasite adapted to the drug, new measures had to be taken in order to battle the protozoan (World Health Organization, 2019). Several chemicals have been created to reduce-- or completely replace-- the dependence on quinine drugs.

In an effort to prevent further Malarial infections, a campaign was established during World War II and up to the 1950s that used DDT as the insecticide of choice in destroying *Anopheles* populations. Insecticide spraying was a common practice inside and outside homes, along neighborhood streets, and direct application to trees and other breeding or resting grounds for the mosquitoes.

Throughout the years, the observation of Malaria deaths has found that children are dying more frequently than adults (World Health Organization, 2019). Adults in endemic regions of Malaria have been exposed to nonlethal forms of the disease in their lifetimes and their bodies have created antibodies to combat the parasitic infection. Because children have not had the time to accumulate these defenses, one infection can prove fatal.

The World Health Organization has estimated that there were 219 million cases of Malaria in 2017, and a death-toll of 435,000 that same year (2019). The World Health Organization's Africa region experiences the highest burden of Malaria morbidity and mortality rates (World Health Organization, 2019). The Centers for Disease Control and Prevention and the World Health Organization have declared that Malaria is both preventable and curable.

Culex

The *Culex* genus of mosquitoes is generally unicolorous and drab in color. They carry the virus that causes West Nile.

West Nile Virus. Symptoms of West Nile Virus can include: fever, head and body aches, and swollen lymph nodes. Progressive symptoms of serious cases can include high fever, disorientation, stiffness, tremors or convulsions, muscle weakness and paralysis, brain damage, coma, or even death. There is no established treatment for the disease, but interferon therapy has shown some signs of being effective during trials (Lawrence & Smith, 2019).

The Centers for Disease Control and Prevention suggest that only 1 in 150 people will acquire West Nile from a mosquito bite (Lawrence & Smith, 2019). Transmission of the disease by mosquitoes is quite low for several reasons: there is a relatively small incidence of infected mosquitoes in a given area, even if the area has a history of West Nile; the virus may also not be present in the mosquito saliva while feeding, therefore being unable to transmit the disease; lastly, if the virus is passed from the mosquito, small amounts of the virus injected may not encourage a full infection (Lawrence & Smith, 2019).

Risk Factors

Social determinants of health are influences on the way people live, work, and play in their environments. Living in poorly constructed shelters or working in an unregulated factory are examples of unsatisfactory determinants of health. The more at risk one is in their everyday lives, the higher the chance of harm to the body and mind. If someone has access to a safe neighborhood and clean air, the greater the chance of living a healthy and happy life.

There are copious amounts of factors that contribute to living a happy and healthy life: from the global economy and climate change to access to clean water and transportation. The large-scale problems and influences can lead directly to health concerns and problems immediately or later in life. Upstream and downstream risk factors directly and indirectly impact the livelihoods of every person on earth.

Upstream Risk Factors

At the macro level, world politics and national governments can heavily influence the health of a population. If a nation has been at war, their industry and infrastructure can be severely underdeveloped due to the lack of workers. The potential laborers are caught up in fighting for their lands, inhibiting the growth of the economy due to lost wages and spending. Without the industry and infrastructure, poverty becomes widespread without places to work and items to sell.

Without supply and demand, the economy of a region can plummet. A poor market makes for difficult trading of goods and services. Higher amounts of imports than exports can further send the economy of a nation into debt that can be impossible to relieve. If an already poor country experiences an influx of difficulties and barriers to success, they run the risk of becoming vulnerable to outside forces.

Climate change is another upstream risk factor for health. Flooding of dry areas and an increase in temperatures provides new habitats to form that can support the life cycle of mosquitoes in areas previously unencumbered. For example, the *Aedes albopictus* has expanded its range within recent years due to the change in climate (Schweisfurth, 2015).

The poor infrastructure, accentuated by a struggling economy, and an increase in vectors of an area are upstream risk factors that can impact a person's health and cause downstream risk factors that affect individuals personally.

Downstream Risk Factors

Death, disease, and disability are all possible outcomes of an upstream risk factors' impact. The poverty created by war or a failing economy keeps families from building the best homes, buying protective clothing, or maintaining an insecticide-treated bed net. Without these measures to protect against mosquito-borne diseases, the people most hard-hit by these tragedies are at a greater risk of infection. Adults that have jobs can lose time and money by being bed-ridden, while children are unable to attend school; having less money than needed and remaining uneducated are just two social determinants of health that can cause inequality within a population.

If a disease is left untreated and allowed to spread in a population, an increase in the morbidity rate will be observed. And if the cycle continues, serious problems can arise. Permanent loss of bodily autonomy can negatively impact a person's livelihood and their position within their community. Socioeconomic status is an important indicator of a person's health.

Not everyone who contracts a mosquito-borne disease will remain permanently hindered by the experience, but for those who are affected, life may never be the same. Mosquito bites are a preventable occurrence if given the correct materials, but for some, it is nearly impossible to come up with the money, time, or commitment required to remain healthy.

Global Response

There are a multitude of organizations, funds, projects, and missions focused on lessening the burden of disease from affected communities, yet, more work is still needed. There a several methods employed to reduce mosquito borne diseases. More hands-on approaches to mosquito abatement like the physical dumping of stagnant water are a common ploy in areas, but biological efforts like the introduction of *Wolbachia* are also being made to reduce the mosquito population. Instead of targeting the mosquito population, some programs are just issuing physical barriers as a means of protection.

As with any form of intervention implementation, there are always pros and cons associated with each method. A table of current evidence-based interventions (Table 2) has been provided to show a multitude of approaches and if they are an effective method of decreasing mosquito borne diseases. These approaches, whether found to be effective or ineffective, will be considered using a data driven model (Figure 3)-- compiled of current interventions, their approaches and goals, and their effectiveness-- created solely to compare the rates of morbidity and mortality in Sub-Saharan Africa to their levels of infrastructure that are determined by the area's economy.

Global aid has been instrumental in lessening the impact of mosquito-borne illnesses in developing countries around the world. According to the *World Malaria Report 2018*, great progress was made between the years of 2010 and 2017 by reducing the cases of malaria by 20 million, thanks to the organizations that help fund eradication programing. But not all eradication initiatives are sustainable or ethical.

Success, but at what cost? With the disbursement of American troops across the world for World War II, new challenges arose that made fighting a war even more difficult. Soldiers were being exposed to new populations of mosquitoes that carried a variety of diseases that had yet to be introduced to the United States. Malaria was on the rise in the deployed men, so the nations' governments decided to introduce insecticidal spray in the latter half of the war. Dichlorodiphenyltrichloroethane, commonly called DDT, was liberally applied to homes, streets, bodies of water, forests, and even people when it was first used around the world. Extensive utilization of DDT lead to harmful environmental impacts.

Research into this chemical revealed that it was extremely harmful for birds, fish, amphibians, and other aquatic organisms (Sanders, 2016). Because DDT is such a stable chemical compound, it can bioaccumulate in the ecosystem. As the chemical moves up the food-chain, the organisms are ingesting larger and larger amounts of the toxic substance with every meal (Sanders, 2016). DDT was banned from agricultural use in the United States, and later banned around the world, because of its ability to bioaccumulate (Sanders, 2016). Neurophysiological and reproductive disorders have been attributed to DDT absorption in the body, and DDT has hinted at being carcinogenic to plasma membranes (Sanders, 2016).

The Fight. Even with forward progress, there are always pitfalls. Funding is an issue in many regions of the world, so preventative measures are not always carried out in countries that previously saw a drop in malarial cases. Data collected between 2015 and 2017 revealed no significant decrease in cases of malaria— in fact, some of the countries with the highest burdens reported an *increase* in cases (*World Malaria Report, 2018*).

The plateau in malaria eradication is partly due to the lack of awareness being raised for the disease compared to years prior. Funding is still being provided to the world relief effort, primarily through the United States of America ($1.2 billion; 39% of global contribution), the Development Assistance Committee ($700 million; 21% of global contribution), the United Kingdom of Great Britain and Northern Ireland ($300 million; 9% or global contribution), and the Bill and Melinda Gates Foundation ($100 million; 2% of global contribution) (*World Malaria Report, 2018*).

Community Level Response

Small-scale efforts can be just as effective for community development and stability than the global, large-scale movements (Fraisse, 2018). Grassroot startups are instrumental in providing information and help to their local environments. Groups that come together to educate children and adults are spreading awareness of mosquito-borne diseases and how to better help keep them out of the area. Teaching a community to dump containers of water, bird baths, small pools, and upturned tires with accumulated rain water keeps the breeding of mosquitoes out of their backyards.

Scientific Community's Response

The introduction of *Wolbachia* bacterium is an experimental influencer on the spread of mosquito populations and diseases. Certain strains of *Wolbachia* bacteria have been shown to reduce the vectoral capacity of mosquitoes in lab settings. These bacteria can either inhibit the growth of the viral or parasitic causes of mosquito-borne diseases *or* reduce the mosquito's lifespan, reducing the amount of time it can breed and feed while infected (Hancock, Sinkins, and Godfrey, 2011).

The key to introducing *Wolbachia* infected mosquitoes is to have a higher release rate of male mosquitoes than female (Hancock, Sinkins, and Godfrey, 2011). Female mosquitoes are the only ones responsible for nuisance biting and diseases transmission, but infected females must also be released. If male and female mosquitoes that are both infected with the bacteria mate, the eggs produced from the pair will not hatch, which will reduce mosquito populations (Hancock, Sinkins, and Godfrey, 2011). If an infected male mates with an uninfected female, the offspring will be infected; similarly, if an infected female mates with a male mosquito, their offspring will also be born with the *Wolbachia* infection (Hancock, Sinkins, and Godfrey, 2011).

Models developed by Hancock, Sinkins, and Godfrey (2011) show that once *Wolbachia* has become established in a mosquito population, the rate of mosquito-borne diseases will be reduced due to the inhibition of pathogen transmission and diminishing adult mosquito lifespans.

Current Study

Regions of Interest

The following section details three distinct world regions in order to provide comparison of upstream and downstream factors between economic, political, and environmental climates. These three regions were decided upon for various reasons, including economic status, burden of disease, military activity, and health and education expenditures.

Niger

Ranked as the second *least* developed country in the world by the United Nations, Niger is at a very high degree of risk for major infectious diseases from food, water, and vector borne sources. The country is very susceptible to Malaria and Dengue Fever due to the majority of the population living in the southern-most tropical regions. Because the northern 4/5ths of the country is desert, the southern region hosts 16.5% of the population in urban living, leaving the other 83.5% to live in rural areas throughout the south.

Agriculture is the nation's staple livelihood; 35.1% of the land is dedicated to growing crops and grazing livestock. With an abundance of hosts in one region of the country, mosquitoes have a large source for their blood meals. The animals and people that live in close proximity to each other and in mosquito-loving habitats are at risk for being fed on and contracting mosquito-borne diseases.

South Sudan

South Sudan is one of the poorest countries in the world and has some of the lowest socioeconomic statuses. The country formed from Sudan in 2011 after many years of civil war, and skirmishes are still occurring. Education and infrastructure are abysmal because of tensions between Sudan and South Sudan, government and rebel groups, and community violence, leaving little room for improvement. Many adults remain uneducated because of the decades of fighting before secession from Sudan.

Agriculture provides 100% of land use coverage for the country, which the vast majority of the population is reliant upon. Less than 20% of the population lives in an urban environment, while the other 80% populate the rural areas. The world's largest wetland, The Sudd, dominates the northern border, making the entire country a breeding ground for mosquitoes and the diseases they carry. Malaria and Dengue Fever heavily saturate the population as major infectious diseases.

United States of America

While the United States shares climate types similar to Niger and South Sudan in certain regions, the burden of mosquito-borne disease is much lower. Large urban clusters in the form of mega cities and larger metropolitan areas account for 82.5% of the population of the United States. These densely populated areas have a limited amount of green space hospitable to mosquito breeding. The high percentage of improved drinking water and sanitation facilities provide a level of security against a large amount of diseases.

While the United States' infrastructure is subpar in some areas, access to more remote locations are accessible through air travel or off-road vehicles belonging to emergency services.

Mapping the Regions

Converting abstract observations of physical features and events (geographical representations) into a visualization of these attributes in a geographic model or map (cartographic representation) is the essence of cartography. Maps are a simplification or approximation of reality, and they must be selective and symbolic. Several thematic models of the earth--comparing

Niger, South Sudan, and the United States-- were generated in order to show how the population of a region and gross domestic product (GDP) rates impact infrastructure and the distribution of mosquito-borne diseases.

Table 1 (in appendices) has been compiled to show each of the three regions and how they compare to each other via population density, demographic shifts from urban to rural populations, improved sanitation percentages, GDP, and health and education expenditures.

Methods

Using ArcMap and ArcOnline, which are Esri GIS applications provided by the university for geography students, the models shown in figures 1, 2, and 3 were created. Data for these maps were found from several reliable and credible sources (Centers for Disease Control, Esri, World Population Review, The World Bank, and the United Nations). All data found for this project have been updated within the past four to five years, so the information is current. A shapefile—a polygon that consists of the spatial and geographic data that can be manipulated to showcase different features—of all countries, including the recent formation of South Sudan, is the base map on which all attributes are presented; vector-based models present spatial and geographic data that are integral to thematic maps, so they will be the primary data format models. Figures 1, 2, and 3 are all small-scale maps that present a worldview for easy comparison, rather than an up-close examination that cannot provide an instant recognition of differences and similarities between the regions. The projection of the maps takes the three-dimensional, geoid shape of the earth and flattens it into a two dimensional and developable surface.

Results

Figure 1 provides a representation that shows the interval differences between Niger, South Sudan, and the United States' population in rural to urban settings. Niger has a concentration of urban (dull orange) populations in the south of the country. South Sudan is predominately settled in extreme urban (red) areas, with few heavy urban (orange) areas. The United States consists primarily of settled (dark purple) to light urban (tan) areas, with small clusters of urban (dull orange), heavy urban (orange), and extreme urban (red) areas in locations representing larger cities and towns.

Figure 2 is a bivariate map that demonstrates the relationship between populations and the GDP that each country brings in annually. Niger has the smallest classification of point symbology, demonstrating a GDP less than five trillion (5,000,000,000,000). Niger's color scheme is a very pale orange, representing its population on the lower half of the population color gradient (approximately 23 thousand (23,000)). South Sudan is also represented as having the smallest point symbology classification. The South Sudan color (pale creamy orange) shows the population in the bottom quarter of the color gradient scale (approximately 11 thousand (11,000)). The United states has the largest point symbol, showing that it is the country that accumulates the most wealth annually—around 21.3 trillion (21,300,000,000,000). It also has a dark maroon color scheme, indicating a population that is one of the eight regions with the highest population.

Figure 3 presents morbidity rates in each country. Niger is represented by the second largest point symbol for morbidity rates. The symbol recognizes morbidity rates between 80 deaths out of 1,000 live births and 110 deaths out of 1,000 live births. Niger's morbidity rate is 81.1 deaths out of 1,000 live births. South Sudan has the third largest point symbol for morbidity rates. This symbol recognizes rates between 60 deaths out of 1,000 live births and 80 deaths out of 1,000 live births. South Sudan's morbidity rate is 62.8 deaths for every 1,000 live births. The United States point symbol indicates one of the lowest rates of morbidity. The smallest point symbol recognizes morbidity rates less than 6 deaths per 1,000 live births. The United States morbidity rate is 5.8 deaths for every 1,000 live births.

Discussion

As the United States is shown to have a higher population, it would be expected that there would also be a higher incidence/prevalence of mosquito-borne diseases/morbidity or mortality rates because of the large amount of people. However, this is thwarted by the fact that the United States has one of the largest GDPs of all countries in the world. With such a large amount of money being funneled into infrastructure, health care, and education, mosquito-borne diseases have greater difficulty increasing in prevalence throughout the country.

At one point in US history, mosquito-borne diseases like Yellow Fever were prevalent along the Mississippi River Valley, Gulf Shores, and along the East coast due to slave trading and infected sailors that travelled to and from endemic countries (Crosby, 2006). After heavy rains in early 1878, the *Aedes aegypti* mosquito population flourished along the Mississippi River (Crosby, 2006). According to Crosby in their work "The American Plague: the Untold Story of Yellow Fever, the Epidemic that Shaped our History," six months after Mardi Gras celebrations, Memphis, Tennessee was a ghost town; revelers that had partied in the streets were sick and dying. Shops had been boarded up, apothecaries and physicians no longer gave out medications and services, and there was no more milk being delivered to family's doorsteps. The city set up a quarantine zone between the Mississippi River and the Wolf River, isolating them from the rest of the country. Cities such as New Orleans, Louisiana and Philadelphia, Pennsylvania were also hard hit by Yellow Fever.

The United States was able to recover from these infections because of the establishment of the United States Public Health Service and considerable funding to prevent any more disasters like the Yellow Fever outbreaks. Being one of the top grossing countries in the world provides the United States with the means to control mosquito populations; improved sanitation and exceptional infrastructure standards keep the mosquito populations and diseases to a minimum.

Niger and South Sudan are both suffering from a lack of income, poor infrastructure, and relatively small health and education expenditures. These two endemic regions currently are not afforded the means to eradicate or dramatically diminish mosquito-borne diseases because of civil wars, struggling economies, and inattentiveness to living improvements. Aid foundations are providing necessary preventative measures like insecticide-treated bed nets and diagnostics, but without the governments' focus on improving poverty levels and country-wide infrastructure that provides access to health facilities and other means of self-improvement, the problems that come with mosquito infestations will never be resolved.

Conclusion

The preventative measures aimed at reducing the incidence of mosquito-borne disease supplied to countries around the world are a good initial step in bringing down mosquito-borne disease incidence and prevalence rates, but more needs to be done in order to combat and eradicate these diseases. Improved economies, infrastructure, and poverty levels are crucial in ending the days of death by mosquito. All countries facing endemic mosquito-borne diseases should contribute more of their GDP to healthcare and education expenditure. Increased money to healthcare would provide individuals the ability to receive treatment to help them battle mosquito-borne illnesses. With an increase of money going towards education, students would be able to recognize symptoms of disease or be able to more closely monitor the amount of water-collecting containers around their communities.

Spending on healthcare and education, improved sanitation and water sources, and sufficient infrastructure are the priority influences of mosquito-borne disease rates. All of those factors are based upon a country's annual income. If a country is grappling with the ability to compete in the world market or fighting civil wars, their priorities are not focused on eradicating diseases like

Chikungunya, Dengue, Malaria, Yellow Fever, West Nile virus, or Zika. Morbidity and mortality rates in countries that are endemic with mosquito-borne diseases are heavily influenced by what is happening at the macro level of the world economy. Finding ways to bolster economies indefinitely and self-sufficiently can be the only way that every struggling country in the world will be able to effectively combat diseases that disproportionately affect poor infrastructure areas. The figures provided in the appendices (Figures 1, 2, and 3) show how both the upstream and downstream risk factors affect a country's world standing in population, GDP, and morbidity.

References

2017: A Year of Impact. (2018, February 5). Retrieved from https://nothingbutnets.net/press-releases/2017-a-year-of-impact.

Annual Report 2018. (n.d.). Retrieved from https://www.gatesfoundation.org/Who-We-Are/Resources-and-Media/Annual-Reports/Annual-Report-2018.

Banerjee, A., Duflo, E., & Qian, N. (2012). *On the road: Access to transportation infrastructure and economic growth in China* (No. w17897). National Bureau of Economic Research.

Bausch, D. G., & Schwarz, L. (2014). Outbreak of Ebola virus disease in Guinea: where ecology meets economy.

Bill & Melinda Gates Foundation. (n.d.). Malaria. Retrieved from https://www.gatesfoundation.org/what-we-do/global-health/malaria.

Blum, D., & Feachem, R. G. (1983). Measuring the impact of water supply and sanitation investments on diarrhoeal diseases: problems of methodology. *International journal of epidemiology*, *12*(3), 357-365.

CDC - Malaria - Malaria Worldwide - How Can Malaria Cases and Deaths Be Reduced? - Insecticide-Treated Bed Nets. (2019, January 4). Retrieved from https://www.cdc.gov/malaria/malaria_worldwide/reduction/itn.html.

Chukwuocha, U., Okpanma, A., Nwakwuo, G., & Dozie, I. (2014). Determinants of Delay in Seeking Malaria Treatment for Children Under-Five Years in Parts of

South Eastern Nigeria. Journal of Community Health, 39(6), 1171–1178. https://doi.org/10.1007/s10900-014-9872-4.

Control. (n.d.). Retrieved from https://www.mosquito.org/page/control.

Crosby, M. C. (2006). The American plague : the untold story of yellow fever, the epidemic that shaped our history. Berkley Books.

Fact sheet about Malaria. (n.d.). Retrieved from https://www.who.int/news-room/fact-sheets/detail/malaria.

Fraisse, L. (2018). Potential and ambivalent effects of grassroots initiatives on neighbourhood development.

Ganesan, V. K., Bin Duan, & Reid, S. P. (2017). Chikungunya Virus: Pathophysiology, Mechanism, and Modeling. Viruses (1999-4915), 9(12), 368. https://doi.org/10.3390/v9120368

GDP by Country. (n.d.). Retrieved from https://www.worldometers.info/gdp/gdp-by-country/.Geographic Distribution. (2019, September 19). Retrieved from https://www.cdc.gov/chikungunya/geo/index.html.

Haug, Charlotte J., Marie Paule Kieny, and Bernadette Murgue. "The Zika Challenge." The New England Journal of Medicine, vol. 374, no. 19, 2016, pp. 1801–3.

Hancock, P. A., Sinkins, S. P., & Godfray, H. C. J. (2011). Strategies for Introducing Wolbachia to Reduce Transmission of Mosquito-Borne Diseases. PLoS Neglected Tropical Diseases, 5(4), 1–10. https://doi.org/10.1371/journal.pntd.0001024

Integrated Mosquito Management. (2018, December 10). Retrieved from https://www.cdc.gov/westnile/vectorcontrol/integrated_mosquito_management.html.

Kushitor, M. K., & Boatemaa, S. (2018). The double burden of disease and the challenge of health access: Evidence from Access, Bottlenecks, Cost and Equity facility survey in Ghana. *PLoS ONE*, *13*(3), 1–11. https://doi.org/10.1371/journal.pone.0194677

Lawrence, D. M., & Smith, D. G. . P. D. (2019). West Nile virus. Magill's Medical Guide (Online Edition). Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=shib&db=ers&AN=86196464&site=eds-live&scope=site

Limao, N., & Venables, A. J. (2001). Infrastructure, geographical disadvantage, transport costs, and trade. *The World Bank Economic Review*, *15*(3), 451-479.

Lum, F.M.; Ng, L.F.P.(2015). Cellular and molecular mechanisms of chikungunya pathogenesis. Antivir. Res. 120, 165–174.

Monitoring and evaluation of programmes. (2017, January 3). Retrieved from https://www.who.int/denguecontrol/monitoring/en/.

Msellemu, D., Shemdoe, A., Makungu, C., Mlacha, Y., Kannady, K., Dongus1, 2,3,5, Stefan, … Dillip, A. (2017). The underlying reasons for very high levels of bed net use, and higher malaria infection prevalence among bed net users than non-users in the Tanzanian city of Dar es Salaam: a qualitative study. Malaria Journal, 16, 1–10. https://doi.org/10.1186/s12936-017-2067-6

Ogun, T. P. (2010). Infrastructure and poverty reduction: Implications for urban development in Nigeria. In *Urban Forum* (Vol. 21, No. 3, pp. 249-266). Springer Netherlands.

Pinstrup-Andersen, P., & Shimokawa, S. (2007). Rural infrastructure and agricultural development. *ABCDE*, 175.

Reutlinger, S. (1986). *Poverty and Hunger: Issues and Options for Food Security in Developing Countries. A World Bank Policy Study*. The World Bank, 1818 H Street, NW, Washington, DC 20433.

Rougeron, V.; Sam, I.C.; Caron, M.; Nkoghe, D.; Leroy, E.; Roques, P. Chikungunya, a paradigm of neglected tropical disease that emerged to be a new health global risk. J. Clin. Virol. 2015, 64, 144–152.

Sanders, K. (2016). DDT : Properties, Uses and Toxicity. Hauppauge, New York: Nova Science Publishers, Inc. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=shib&db=nlebk&AN=1406237&site=eds-live&scope=site

Schnee, A. (2018). Zika virus. Salem Press Encyclopedia of Health. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=shib&db=ers&AN=113928186&site=eds-live&scope=site

Schweisfurth, H. (2015). Climate Change and Disease. Berlin: Nora. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=shib&db=nlebk&AN=1654673&site=eds-live&scope=site

Selendy, J. M. (Ed.). (2011). *Water and sanitation-related diseases and the environment: challenges, interventions, and preventive measures*. John Wiley & Sons.

Sen, A. (1998). Mortality as an indicator of economic success and failure. *The economic journal*, *108*(446), 1-25.

Sengupta, S. P. D. (2019). Dengue fever. Magill's Medical Guide (Online Edition). Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=shib&db=ers&AN=86194048&site=eds-live&scope=site

Smith, D. G., PhD. (2019). Yellow fever. Magill's Medical Guide (Online Edition). Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=shib&db=ers&AN=86196469&site=eds-live&scope=site

Thiberville, S.D.; Moyen, N.; Dupuis-Maguiraga, L.; Nougairede, A.; Gould, E.A.; Roques, P.; de Lamballerie, X. (2013). Chikungunya fever: Epidemiology, clinical syndrome, pathogenesis and therapy. Antivir. Res. 99, 345–370.

Yactayo, S.; Staples, J.E.; Millot, V.; Cibrelus, L.; Ramon-Pardo, P. Epidemiology of chikungunya in the Americas. J. Infect. Dis. 2016, 214, S441–S445.

The World Factbook: Niger. (2018, February 1). Retrieved from https://www.cia.gov/library/publications/resources/the-world-factbook/geos/ng.html.

The World Factbook: South Sudan. (2018, February 1). Retrieved from https://www.cia.gov/library/publications/resources/the-world-factbook/geos/od.html.

The World Factbook: United States. (2018, February 1). Retrieved from https://www.cia.gov/library/publications/resources/the-world-factbook/geos/us.html.

World Health Organization. (2018). World malaria report 2018. Geneva.

Appendices

Appendix A.

Figure 1.

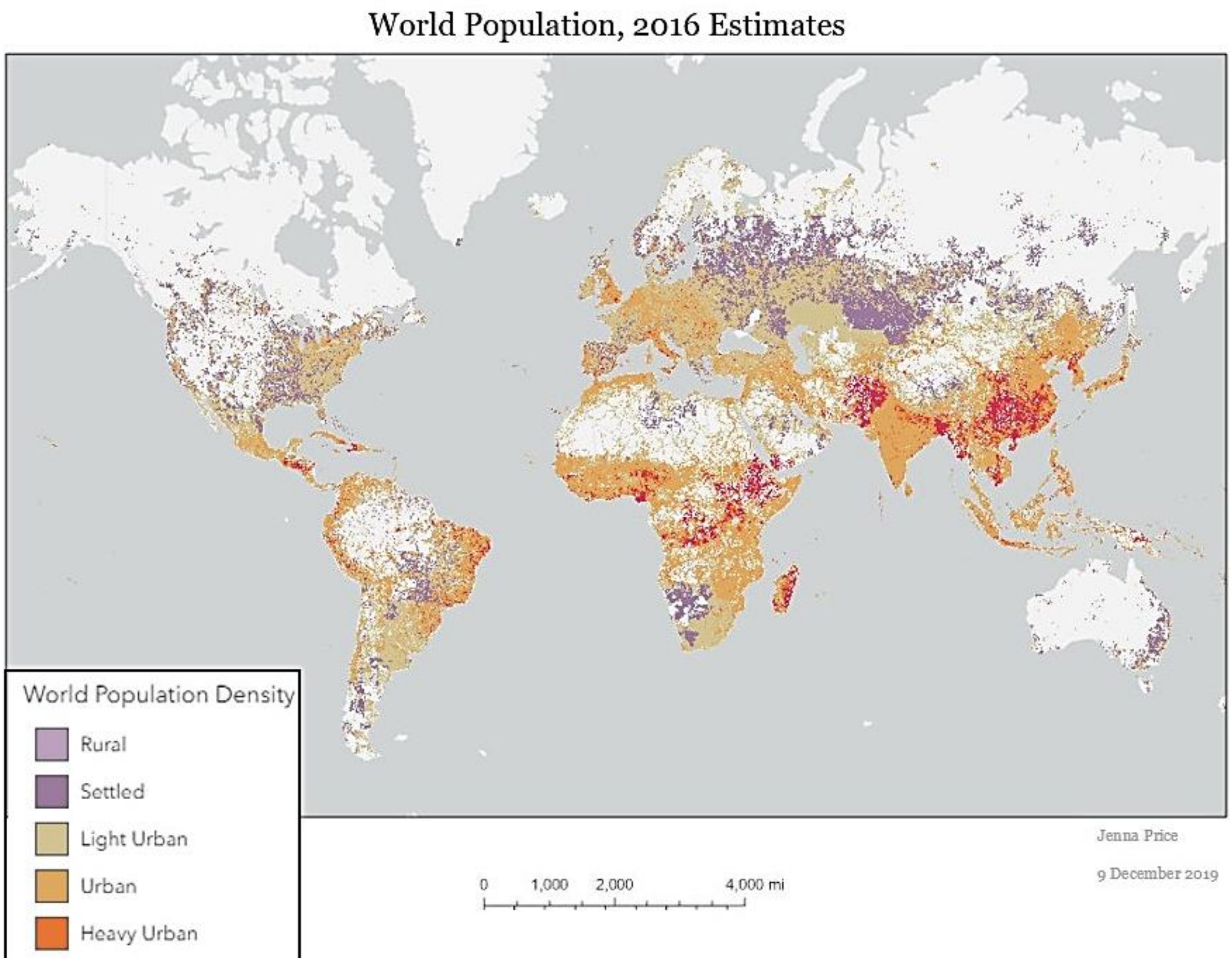


Figure 2.

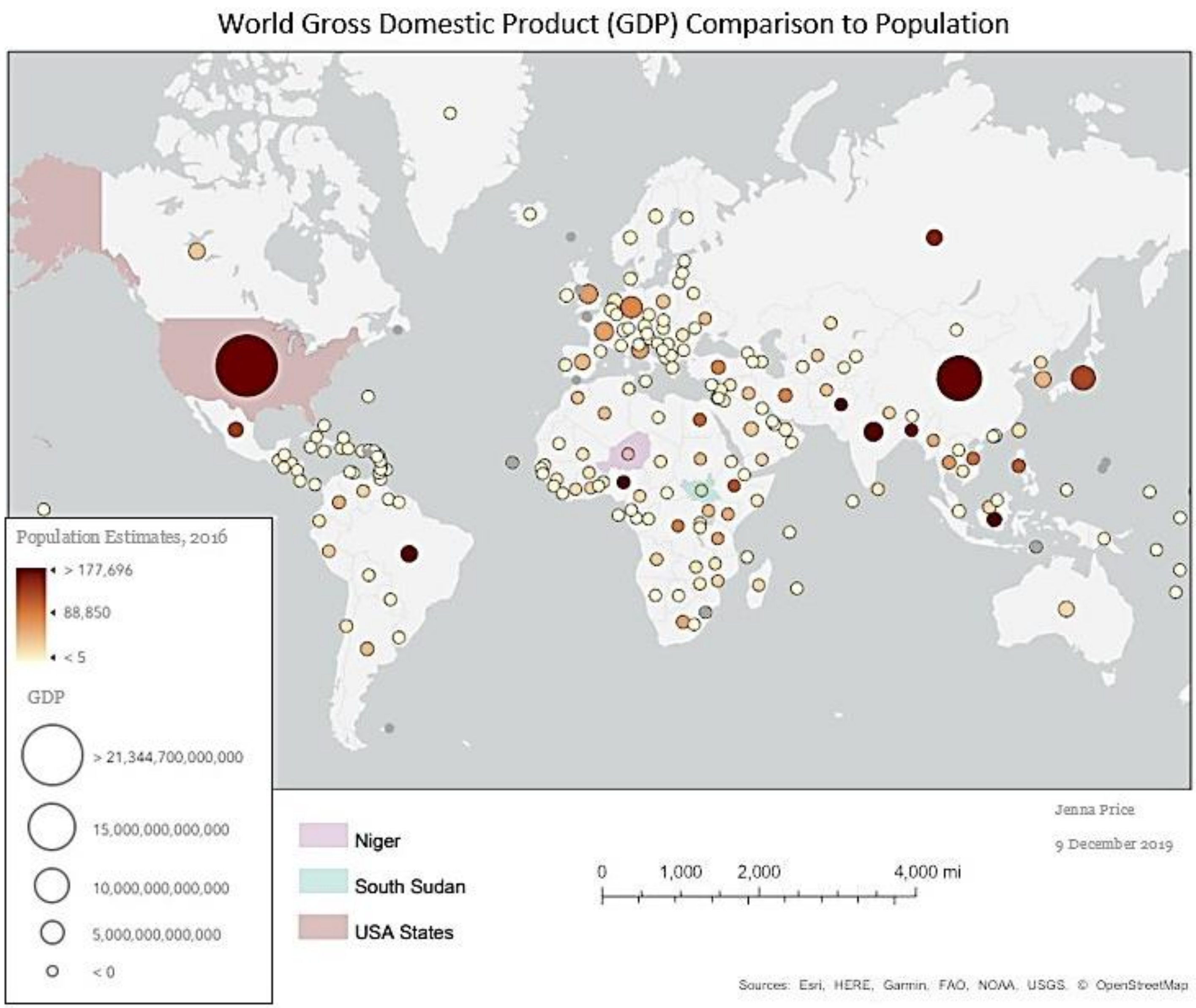
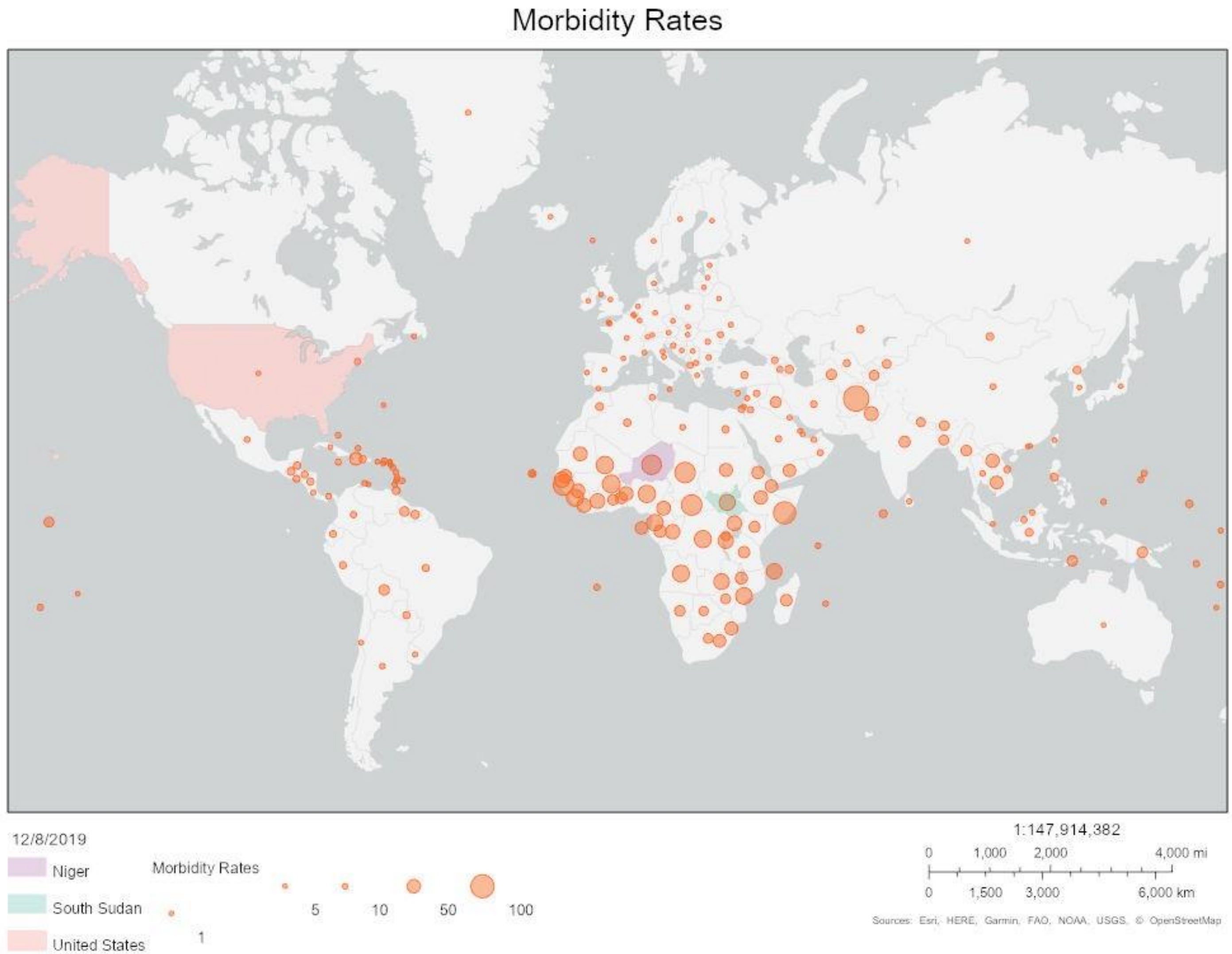

World Gross Domestic Product (GDP) Comparison to Population
Population Estimates, 2016
> 177,696
88,850
< 5
GDP
> 21,344,700,000,000
15,000,000,000,000
10,000,000,000,000
5,000,000,000,000
< 0
Niger
South Sudan
USA States
0 1,000 2,000 4,000 mi
Jenna Price
9 December 2019
Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap

Figure 3.


Morbidity Rates
12/8/2019
Niger
South Sudan
United States
Morbidity Rates
1
5
10
50
100
1:147,914,382
0 1,000 2,000 4,000 mi
0 1,500 3,000 6,000 km
Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap

Appendix B

Table 1:

Region	*Total Population*	*Demographic Shift (Urban/Rural)*	*Sanitation-Improved (Urban/Rural)*	*GDP ($)*	*Reported Malarial Cases (Millions)*	*Health Expenditure*	*Education Expenditure*
Niger	19.9 Million	16.5%/83.5%	37.9%/4.6%	8.224 Billion	2.76	7.2%	3.5%
South Sudan	10.2 Million	19.9%/81.1%	16.4%/4.5%	3.06 Billion	1.49	2.5%	1%
United States	329.3 Million	82.5%/18.5%	100%/100%	19.49 Trillion	N/A	16.8%	5%

All data comes from the CIA World Factbook for each respective country.

The World Factbook: Niger. (2018, February 1). Retrieved from https://www.cia.gov/library/publications/resources/the-world-factbook/geos/ng.html.
The World Factbook: South Sudan. (2018, February 1). Retrieved from https://www.cia.gov/library/publications/resources/the-world-factbook/geos/od.html.
The World Factbook: United States. (2018, February 1). Retrieved from https://www.cia.gov/library/publications/resources/the-world-factbook/geos/us.html.

Table 2:

INTERVENTIONS	*DESCRIPTION OF METHODS*	*ONGOING EFFORT*	*EFFICIENCY/EFFICACY*
BILL & MELINDA GATES FOUNDATION	"… to be catalytic in reducing the burden of malaria and accelerating progress toward eradication of the disease."[3]	Investment of an additional $1 Billion dollars through 2023 to the research and development in reducing the burden of disease. Match funds of up to £50 million on behalf of the United Kingdom's Malaria Match Fund Commitment to The Global Fund.[10]	Combined efforts with global organizations and communities found the first approved treatment for relapsing malaria in the past 60 years, and close to one billion people were treated for Neglected Tropical Diseases in 2018.[2]
WORLD HEALTH ORGANIZATION	Implementation of monitoring and evaluation programs to continuously track the spread of mosquito-borne diseases. Their aim is to estimate and track the spread and burden of disease for efficiency of methods and as a record-keeping organization.[8]	1. Diseases surveillance: tracking prevalence and incidence numbers.[8] 2. Vector surveillance: tracking *Aedes, Anopheles, and Culex* mosquito species to determine density and potential risk.[8] 3. Monitoring behavioral impact: tracking whether preventative measures are being adopted and supported in communities.[8]	Efforts have been shown to reduce malaria cases by nearly 20 million from the years 2010 to 2017.[10] Progress plateaued between the years 2015 and 2017, showing no significant reduction of malarial cases worldwide.[10]
INSECTICIDE SPRAYING	"Pesticides may be applied to control larvae (larvicides) or adults (adulticides). Applications of [pesticides] are made after the presence of mosquitoes has been	Insecticidal spraying can occur outdoors where trees, smaller bodies of water, and vegetation harbor the vectors; or it can occur indoors with the spraying of walls in homes and public buildings.	Integrated mosquito management or integrated vector management has been shown to significantly reduce mosquito populations when followed correctly.[7]

	demonstrated by surveillance procedures.”[5]		
INSECTICIDE-TREATED BED NETS	“Bed nets reduce malaria-related illness and deaths, by forming a protective barrier around people sleeping under them. When impregnated with long-lasting insecticide formulations they also repel or kill mosquitoes attempting to feed upon sleeping humans, and can even suppress entire populations of… vectors…”[9]	Many groups, aid foundations, and organizations continue to partner together and donate insecticide treated be nets to vulnerable populations every year.	Insecticide-treated bed nets have been shown to reduce the amount of death seen in children <5 years of age from all mosquito-borne diseases by around 20%.[4]
UNITED NATIONS	Partners with other organizations to bring about change around the world. The UN has partnered with #NothingButNets to help save lives and defeat Malaria. This movement distributed over 700,000 bed nets in 2017, along with malarial treatments and diagnostics.[1]	At the end of 2017, #NothingButNets partnered with others to help fight and end malaria in the Americas.[1]	In #NothingButNets 11 year history, they have distributed over 12 million bed nets and have protected more than 24 million people with their interventions.[1]
***WOLBACHIA* BACTERIA**	*Wolbachia*-mosquito interactions can reduce the vectoral capacity of mosquitoes, therefore minimizing and controlling the spread of mosquito-borne diseases.[6]	Establishment of *Wolbachia* in wild mosquito populations can be achieved through the release of primarily male mosquitoes, as long as their infection frequency reaches a threshold in the field. Larger sizes and greater amounts of male-	As it has not yet been rolled out due to environmental and ecological concerns, there is no concrete evidence as to its effectiveness. But models have shown a promising reduction in the transmission of mosquito-

		biased releases should provide a greater benefit and would limit the addition of the biting females.[6]	borne disease with the establishment of *Wolbachia* in mosquito populations.[6]