Web GIS as a Disease Management Workspace: Enabling Advocacy at Multiple Scales Across Multiple Continents with the Case of Tungiasis

by

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For Homer and Wilma

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List of Abbreviations

AGOL	ArcGIS Online
AIDS	Acquired immune deficiency syndrome
API	Application programming interface
CBO	Community-based organization
CDC	Centers for Disease Control and Prevention
CFEP	Chigoe Flea Eradication Project
CMV	Customizable map viewer
CSV	Comma separated values
DE	Diatomaceous earth
DNDi	Drugs for Neglected Diseases initiative
DOI	Digital object identifier
EDC	Esri Development Center
EGDB	Enterprise geodatabase
ELA	Enterprise License Agreement
EPSD	Epidermal parasitic skin disease
ERD	Entity-relationship diagram
EULA	End user license agreement
FAO	Food and Agriculture Organization of the United Nations
FLAU	First-level administrative unit
FOSS	Free and open source software
GADM	Database of Global Administrative Areas
GAHI	Global Atlas of Helminth Infections

GAT	Global Atlas of Trachoma
GCS	Geographic coordinate system
GIS	Geographic information system
GISci	Geographic information science
GNTD	Global Neglected Tropical Diseases (database)
GPS	Global Positioning System
GTMP	Global Trachoma Mapping Project
GUI	Graphical user interface
GWD	Guinea worm disease
HIV	Human immunodeficiency virus
HTTP	Hypertext transport protocol
IC	Integrated control
IGO	Inter-governmental organization
ILRI	International Livestock Research Institute
ITI	International Trachoma Initiative
ITN	Insecticide-treated bed nets
KEMRI	Kenya Medical Research Institute
KML	Keyhole markup language
LF	Lymphatic filariasis
MDA	Mass drug administration
MLA	Master License Agreement
MLEM	WHO Model Lists of Essential Medicines
NGO	Non-governmental organization

NLM	United States National Library of Medicine
NPO	Non-profit organization
NTD	Neglected tropical disease
NTD MT	NTD Mapping Tool
NTD-STAG	Strategic and Technical Advisory Group for Neglected Tropical Diseases
OGC	Open Geospatial Consortium
OOB	Out-of-box
OSM	OpenStreetMap
PC	Preventative Chemotherapy
PCS	Projected coordinate system
PDF	Portable document format
PHP	Hypertext preprocessor
PLOS	Public Library of Science
PGIS	Participatory GIS
RDBMS	Relational database management system
REST	Representational State Transfer
QGIS	formerly Quantum GIS
SAAS	Software-as-a-service
SDK	Software development kit
SRTM	Shuttle Radar Topography Mission
SSA	Sub-Saharan Africa
SSI	Spatial Sciences Institute
STH	Soil-transmitted helminth

TALA	Trypanosomaiasis and Land Use in Africa
UN	United Nations
UNICEF	United Nations Children’s Fund
URI	Uniform Resource Identifiers
URL	Uniform resource locator
USC	University of Southern California
USD	United States Dollars
VGI	Volunteered geographic information
VM	Virtual machine
WASH	Water, Sanitation and Hygiene
WAB	Web AppBuilder
WAP	Water access points
WHO	World Health Organization
WRI	World Resources Institute

Abstract

This thesis discusses the author's inception and development of the Chigoe Flea Eradication Project (CFEP) and Tungiasis eLibrary web mapping applications, created to raise awareness about and actively combat tungiasis, a disease of poverty caused by the microscopic flea *Tunga penetrans*. The CFEP was designed to illustrate the efficacy of web GIS as a disease management strategy by establishing a collaborative virtual workspace for aid workers, aid organizations, and governments of afflicted regions. The apps empower the movement of epidemiological data from the local scale to the global scale using volunteered geographic information (VGI). Community aid workers can use the CFEP to track the provision of field surgeries, shoes, and medicine, to record patient demographic data, and to document the use of pesticides in sleeping shelters and communal areas during visits to stricken villages. At a regional scale, aid groups involved in tungiasis prevention and education are invited to provide contact information and delineate service boundaries on a map using the CFEP interface. The second app, the Tungiasis eLibrary, was developed in response to recent changes in World Health Organization (WHO) policy creating a pathway to assign new diseases to the neglected tropical disease (NTD) classification, which introduces greater opportunities for awareness and funding. As part of a reclassification request, WHO member states or regions are invited to submit a petition including a profile of the disease and its distribution. The Tungiasis eLibrary, a collection of georeferenced scientific literature pertaining to the disease, was designed with the intent to serve as that profile for tungiasis. The eLibrary app is populated by VGI in the form of scientific literature, white papers, and data contributed to the eLibrary by researchers and activists. Additionally, the collected articles are displayed on a global map, developing the first-ever authoritative global spatial distribution of tungiasis.

This thesis reviews current NTD-related web GIS applications and describes the programmatic development of the CFEP and eLibrary applications. Advantages and drawbacks of VGI and participatory GIS are explored and an argument is presented that a VGI-generated web GIS empowers state-level actors to report finer-scale data directly to larger actors, providing an avenue for locally-based organizations to contribute valuable ground truths to agencies higher in the hierarchy. The resulting collection of articles comprising the eLibrary is analyzed, and feedback from interested parties that ultimately helped inform the final application is discussed. Ultimately, this research examines web GIS as a collaborative platform for disparate groups to combat a dispersed disease vector and to facilitate the movement of information from the local to the global scale. In this way, web GIS can be used to advocate for change at multiple geographic scales with multiple goals in mind.

Chapter 1 Introduction

Since Dr. John Snow first plotted cholera deaths as points on a map of London in 1854, public health professionals and epidemiologists have embraced the value of maps in disease management. In the field of public health, the roles of geography, geographic information science (GI Science) and geographic information systems (GIS) have changed as well, moving from after-the-fact analysis to prediction, prevention, and proactivity. Organizations like the World Health Organization (WHO), the Carter Center, and the Centers for Disease Control and Prevention (CDC) now routinely use maps and web mapping applications to disseminate up-to-date information about diseases and perform real-time analyses, often tracking outbreaks of serious diseases like Ebola, (the Ebola Portal at https://who-ocr.github.io/ebola-data/) and Zika (CDC at https://www.cdc.gov/zika/geo/active-countries.html). In addition to analysis, these public health organizations also monitor the distribution and incidence of the "big three"—human immunodeficiency virus/acquired immune deficiency syndrome (HIV/AIDS), tuberculosis, and malaria (the Malaria Atlas Project at http://www.map.ox.ac.uk/map/). These maps and mapping applications are a form of "web GIS," or browser-based GIS applications.

Despite the blending of epidemiology and geography for the "big three," epidemiologists who study other diseases have not wholly embraced the technology. One reason for this may be that many diseases are largely ignored due to a lack of publicity or government resources. The WHO has classified seventeen of these as Neglected Tropical Diseases (NTDs), conditions and illnesses that affect the extreme poor in developing tropical regions. With that classification comes funding and awareness, with modest to incredible successes in some cases.

With the acknowledgment that other under-represented diseases and conditions might benefit from the NTD status, in May 2016 the WHO released a roadmap for disease reclassification, requiring the inclusion of a “dossier” of information about the disease and its distribution as part of the petition. Each WHO member state or region is invited to submit a request to the WHO Strategic Advisory Group on NTDs (WHO STAG) for reclassification of endemic diseases and conditions. In this vein, this thesis suggests a third use for GIS within the public health sphere, combining academic research, volunteered geographic information (VGI), collaboration across disciplines, and advocacy to produce a duo of web GIS apps purpose-built to fulfill WHO requirements for disease reclassification *and* local epidemiological disease management.

This thesis project focuses on one epidermal parasitic skin disease (EPSD) called tungiasis, and the creation of easy-to-use, publicly available web mapping applications deployed to assist aid workers, researchers, and governments working toward its management. EPSDs are skin diseases and conditions caused by the presence of parasitic arthropods, such as lice, fleas, or mites. To increase awareness and funding for management of tungiasis, this thesis project constructed two innovative web GIS applications to serve both as the required “dossier” of literature that WHO member states must deliver when petitioning for NTD status for tungiasis, and also to serve local stakeholders, called the Tungiasis eLibrary and Chigoe Flea Eradication Project (CFEP), respectively.

This thesis includes a review of other similar web-based applications including the Global Atlas of Trachoma (GAT), the Global Atlas of Helminth Infections (GAHI), the Global Neglected Tropical Disease Database (GNTD), and the NTD Mapping Tool (NTD MT) and discusses advantages and drawbacks of each. Potential user groups and user scenarios are considered to ensure the application interfaces developed in this thesis are easy to use for people who may not be familiar with GIS in general, or web mapping specifically.

This chapter first provides background information necessary to understand the motivation for this thesis project, as the topic is socially and medically complex. After a description of the *T. penetrans* parasite and the condition it causes, the criteria for and process to classify NTDs are presented. The WHO standard NTD public health intervention strategies are introduced, followed by an examination of tungiasis' fitness for NTD reclassification. A discussion of the project's research objectives and high-level methodology follows, ending with a description of the layout of the remainder of the thesis.

1.1. Background and Motivation

Despite improved globalization of media and increased attention to problems affecting developing countries, health conditions that affect the extreme poor are often underreported and lack funding to combat. Faced with the frightening statistics of HIV/AIDS infections, the lightning-fast transmission of Ebola, and the horrifying results of Zika infection in pregnant women, it is no surprise that nonlethal diseases in the poorest parts of the world warrant less media attention. In an era when life expectancy has dramatically increased, and modern medicine now enables people in developed countries to live well into their eighties and nineties, a disease that does not outright kill its host is easily overlooked. This thesis project addresses one such disease that causes severe pain and suffering to those afflicted but is largely unknown in the developed world. It is not the mortality but the pain, disfigurement, and social ostracism caused by tungiasis that led the author to select this thesis topic.

The next sections introduce NTDs, describe tungiasis and the parasite that causes it, and detail the recent WHO NTD classification criteria and demonstrate the suitability of tungiasis for inclusion as a NTD. These sections detail the primary motivations for this thesis work, and background information that supports the development of the research objectives presented at the end of this chapter.

1.1.1. Neglected Tropical Diseases

> They are ‘neglected’ because they are often hidden, concentrated in remote rural areas or urban slums and shantytowns. They are silent as the people affected or at risk have little political voice. NTDs inflict massive suffering, with many causing life-long disability and death, stigma, mental distress, and discrimination, especially of girls and women. (WHO STAG 2015)

The WHO has classified 18 diseases of the tropics and subtropics as NTDs (WHO 2016c). NTDs affect over one billion people in 149 countries, and represent a social and economic burden nearly equal to that of HIV/AIDS, malaria, diarrheal diseases, and respiratory infections (WHO 2016c; Brady et al. 2006; Hotez, Molyneux et al. 2007). NTDs have in common their preventability, their tendency to affect only those living in extreme poverty, and their propensity for tropical climates. Lacking adequate sanitation facilities or access to safe drinking water are also major contributing factors, as are cohabitation with livestock and proximity to vector species. Most NTDs are not acutely deadly, and their spread is not virulent—insects and parasites are common vectors rather than human-to-human transmission. Table 1 lists all 18 WHO-recognized NTDs as of May 28, 2016 (WHO 2016c).

Because neglected diseases afflict the poorest of the poor and do not generally lead to international epidemiological emergencies, they attract little media attention. The private sector, in this case the pharmaceutical industry, historically has not considered neglected disease research to be a lucrative investment (WHO 2010; Maciag and Zhang 2010; Bethony et al. 2011; Trouiller et al. 2001; Villa et al. 2009; Seddoh et al. 2013).

Table 1 WHO-Recognized NTDs

Buruli ulcer	Human African trypanosomiasis (sleeping sickness)	Rabies
Chagas disease	Leishmaniosis	Schistosomiasis
Dengue and Chikungunya	Leprosy (Hansen disease)	Soil-transmitted helminthiases
Echinococcosis	Lymphatic filariasis	Taeniasis/Cysticercosis
Endemic treponematoses (Yaws)	Mycetoma	Trachoma
Foodborne trematodiases	Onchocerciasis (river blindness)	Dracunculiasis (guinea-worm disease)

For example, pharmaceutical research and development invested in NTDs fell by $193 million United States dollars (USD) in 2013 (G-Finder 2017), but the Lancet Commission on Investing in Health argued that "much of the burden of NTDs in 1.4 billion of the poorest people in South Asia and SSA could be prevented for an annual cost that is likely well under US$1 billion, and probably around US$300 million to US$400 million per annum, through a combination of community-based MDA and case management" (Seddoh et al. 2013) (mass drug administration, or MDA, is discussed later in this chapter). The Lancet paper provided carefully-calculated and convincing estimates using data from 36 ministries of health in SSA. These seem like insurmountable numbers until one starts to break down U.S. pharmaceutical industry revenues. In 2015, the United States held over 40 percent of the global pharmaceutical market, a share valued at $413 billion USD. Healthcare and pharmaceutical industry digital advertising just in the United States accounted for $1.93 billion USD. Revenues for Pfizer, Johnson & Johnson and Merck & Co were $5.2 billion USD, $71.8 billion USD, and $3.9 billion USD, respectively (Statista 2017). These discouraging numbers make it wholly clear that, economically, there has been little incentive for big pharma fiscal investment in NTD medicine research and development (WHO 2010).

In fact, many companies do donate drugs and treatment for NTDs. Johnson & Johnson started the Vaseline Healing Project to provide dermatological care, petroleum jelly, and medical supplies through its partnership with Direct Relief to populations lacking adequate medical resources (Vaseline Healing Project 2017) and 13 drug companies including Pfizer, Merck, Johnson & Johnson, Sanofi, GlaxoSmithKline and Novartis in 2012 pledged to donate an average of 1.4 billion treatments a year to people suffering from NTDs (Kelland 2012). Notable cases include Pfizer, who has agreed to donate an unlimited quantity of azithromycin for the elimination of trachoma, GlaxoSmithKline who will donate up to 600 million tablets of albendazole annually for use in the preventative chemotherapy (PC) of lymphatic filariasis, and Merck Sharpe & Dohme who has agreed to donate an unlimited supply of ivermectin for the treatment of onchocerciasis and lymphatic filariasis—a current annual donation of over 791 million tablets (WHO 2017).

Despite "orphan drug" legislation intended to encourage research and development for rare diseases, the innovation gap for NTDs is growing; some estimates indicate that total R&D for diabetes is more than 15 times that of malaria, and more than 100 times that of other parasitic infections such as hookworm, lymphatic filariasis, and schistosomiasis (Kishore et al. 2010). The United States Orphan Drug Act (1984) has led to commercial and ethical abuses (Wellman-Labadie and Zhou 2009), with many U.S. pharmaceutical companies electing to take advantage of the rare disease incentives to fund R&D for individual cancers that affect less than 200,000 people in the United States, ultimately developing drugs for a marketplace that can absorb exorbitant drug costs (Hillkirk et al. 2017; Tribble 2017; Wellman-Labadie and Zhou 2009;

Herder 2017; Simoens 2011). For example, “of the top 100 drugs in the U.S., the average cost per patient per year for an orphan drug was $140,443 in 2016, compared with $27,756 for a non-orphan” (Tibble 2017; Evaluate 2017). It is increasingly understood that orphan drug development, rather than being an unfortunate economic burden that pharmaceutical companies must bear for the good of all people, is actually quite profitable within the United States (Meekings et al. 2012; Herder 2017; Tribble 2017). Indeed, as of March 20, 2017, the United States Government Accountability Office will investigate potential abuses of the Orphan Drug Act in part because of recent scandals involving five- and six-figure annual price tags (Tribble 2017). While these are examples within the United States, it is important to remember that the United States commands 40% of the global pharmaceutical market, so it is not a stretch to assume that R&D for NTDs (as opposed to diseases within developed nations) is not a top priority within the industry.

According to Bernard Pécoul, executive director of the Geneva-based Drugs for Neglected Diseases initiative (DNDi), it is actually governments that, “need to create the environment and incentives, funds and mechanisms, to stimulate R&D. Intellectual property may have stimulated innovative products in profitable markets, but when you are in a non-profitable market this is no incentive” (Smedley 2015). Unfortunately, most governments faced with these diseases do not have the resources to attract private research even if these governments are willing to admit there is a problem. In some countries, it is preferable, politically, to deny that the problem exists; those constituents that suffer are politically and economically disenfranchised and have no way to report their condition outside their own villages (Maciag and Zhang 2010). Another argument is that universities should lead the charge for NTD research because “they are independent organizations, boast central missions to promote public welfare, and possess copious resources and knowledge to share with partner institutions globally" (Chokshi and Rajkumar 2007; Kishore, Tavera and Hotez 2010). While some NTDs can be temporarily abolished through government-sponsored medical intervention, poverty causing the terrible living conditions that perpetuate these diseases persists and often worsens.

Ironically, advances in modern medicine and advances in technology during the 20th century have contributed to the success of many infectious diseases (Arden 2008). The rise of antibiotics and better prenatal care ensured that more children would survive into adulthood, and improved medical knowledge led to longer adult lives. Reduction of infant mortality has led to an inevitable increase in population density, placing greater socioeconomic and medical burdens on already-struggling communities in developing nations. Improved mobility due to roads enabled the movement of people and things (including diseases) from place to place and increases the chances of transmission and vector dispersal (Feldmeier et al. 2013). The rural to urban migration of the last hundred years has led to unsustainable population densities surrounding cities. This exponential increase in largely non-taxpaying residents often results in the aggregation of unincorporated urban areas, or shantytowns, around existing cities. The municipal governments cannot or will not provide even basic infrastructure within these areas, precluding the availability of potable water and sanitary waste disposal. The ongoing civil wars in developing nations have led millions to flee their homelands, more often than not ending up in informal/improvised settlements or refugee camps, some for years at a time. These living conditions are ripe for diseases of neglect.

The apparent success of guinea-worm disease (GWD) eradication efforts visualizes a path forward for the eradication of other NTDs. An estimated 3.5 million people were infected with guinea worms in the 1980s, but as of January 2016, only three cases of GWD remain (WHO

2016a). In May 2016 Kenya and Sudan requested that the WHO declare their countries GWD-free after three years of no cases (WHO 2016b). The global GWD eradication campaign has been particularly effective, owing largely to both the collaborative development of the LifeStraw® Guinea Worm by Vestergaard and The Carter Center (Callahan et al. 2013) and community-based surveillance initiatives designed to change people's behavior (All Things Considered 2016b). It is argued that changing community perceptions and behaviors is as important to NTD eradication as mass drug administration (MDA). Donald Hopkins, former Director of All Health Programs and currently a Special Advisor for Guinea Worm Eradication at The Carter Center, emphasizes the need for behavioral initiatives to originate within the afflicted communities themselves, claiming it would be a "disaster for outsiders, and by that I mean people from other countries, or even people from outside the community, to come in and demand that people do one thing or another" (St. Fleur 2015). Using GWD as an example, a guinea worm infection causes burning pain that the afflicted attempt to quench by submersing the affected limb in water. This pain is evolutionarily intentional, inflicted by the guinea worm to drive its host to water (it must discharge its larvae in water to reproduce). When an infected host enters water, the worm immediately expels its larvae, effectively contaminating the water source with larval guinea worms. These larvae then infect copepods (microscopic water fleas); when people accidentally ingest the copepods while drinking the water they become infected themselves, and the painful cycle continues. Because it only takes one person or dog with GWD to re-infect an entire village (the "behavior"), GWD-afflicted communities had to implement policies restricting people infected with Guinea worms from entry to local water access points (All Things Considered 2016b). However, establishment of these restrictions and punishment for their violation had to originate from the community leaders, not an outside group; Hopkins' earlier comments refer to this phenomenon. Accordingly, populations also must adopt new behaviors (don’t go in the water when infected) in addition to being provided disease-preventing technology such as LifeStraw® (Callahan et. al. 2103), which provides a physical barrier to prevent ingesting copepods. One without the other will ultimately fail (All Things Considered 2016a). The successful eradication of GWD has done much to spur on work toward the eradication or management of other neglected diseases, and it involved using GIS in ways that had not before been considered (Royal 2013; Royal 2014). Upon learning of GWD-eradication success and Nathaniel Royal’s GIS work, the author began to draw comparisons between GWD and tungiasis, another EPSD that will require the same balance of disease-preventing technology and changing behaviors.

Section 1.1.1. introduced NTDs and discussed the underlying social factors that must be addressed for their successful management, and in one case, eradication. Section 1.1.2. describes *Tunga penetrans* and tungiasis, the disease upon which this thesis is focused.

1.1.2. T. penetrans *and Tungiasis*

It is important to discuss the natural history of *Tunga penetrans (T. penetrans)* and mechanism of infection to understand its peculiar success, as this information is fundamental background required for the design of the web mapping apps developed in this thesis work. *T. penetrans* is a parasitic insect of the order Siphonaptera and the smallest member of the flea family. It is known by a variety of names worldwide, such as jigger, sand flea, Chigoe flea, bicho de pé (foot bug), nigua, or pique. *T. penetrans* is a blood-drinking flea that parasitizes multiple warm-blooded animals. Its presence was recorded by Spanish and Portuguese explorers during the 1500s and is believed to have originated in the Caribbean islands and Central America (Hoeppli 1963; Heukelbach and Ugbomoiko 2007). Indeed, archaeological evidence recently revealed that *T. penetrans* has been endemic to Peru for at least 14 centuries (Maco, Tantaleán, and Gotuzz 2011). The species was introduced to Africa multiple times in the 19th century as a result of the Afro-Caribbean slave trade, spreading across the continent after a ship that departed from Brazil in 1872 discharged its sand ballast in Angola (Feldmeier et al. 2012; Heukelbach and Ugbomoiko 2007). Since then, the flea's range has expanded throughout SSA, affecting primarily poor, rural areas where livestock and humans live in close contact, and more recently overcrowded urban slums. An increase in population density within rural areas, coupled with the construction of roads post-World War II and increasing mobility between settlements, has led to the proliferation of uncontrolled outbreaks (Feldmeier et al. 2013; Feldmeier et al. 2004). Figure 1 is a visualization of the global spatial distribution of *T. penetrans*, derived from data points collected in the Tungiasis eLibrary at the time of this writing.

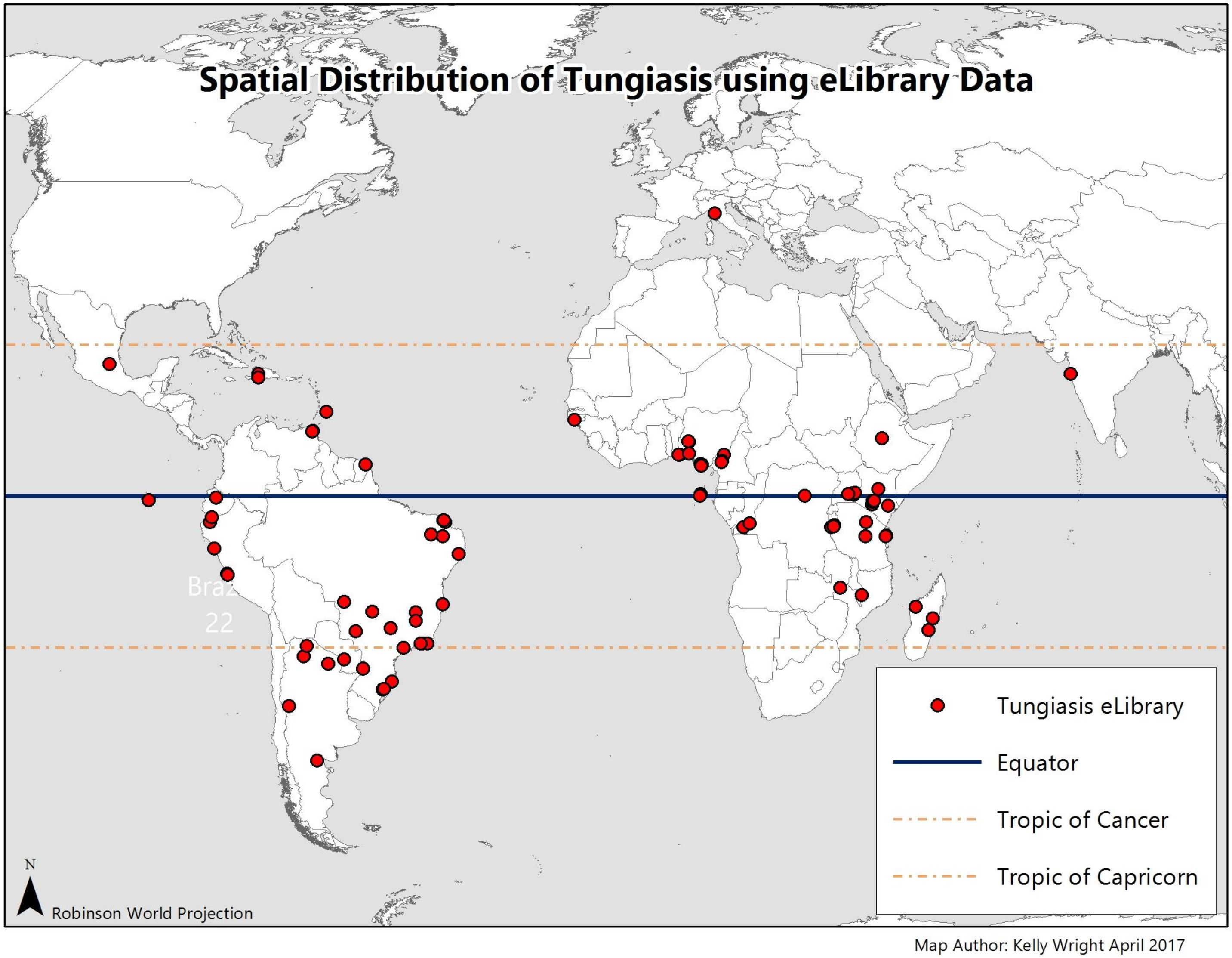


Figure 1 Tungiasis eLibrary-derived Global Spatial Distribution of *Tunga penetrans* based on information in scientific publications contributed as of May, 2017

Tungiasis is an EPSD caused by superinfection of *T. penetrans*. EPSDs occur worldwide but are largely neglected by the scientific community (Feldmeier and Heukelbach 2009; Feldmeier et al. 2014). Geographically, tungiasis affects tropical and subtropical regions in developing nations where poverty is widespread and medical care is difficult to access. Figure 2 illustrates countries where tungiasis is known to be present. *T. penetrans* is endemic to Central and South America, and sub-Saharan Africa (SSA). Globally, over 1 billion people are at risk for the painful and disfiguring disease, most notably children, the elderly, and the physically or

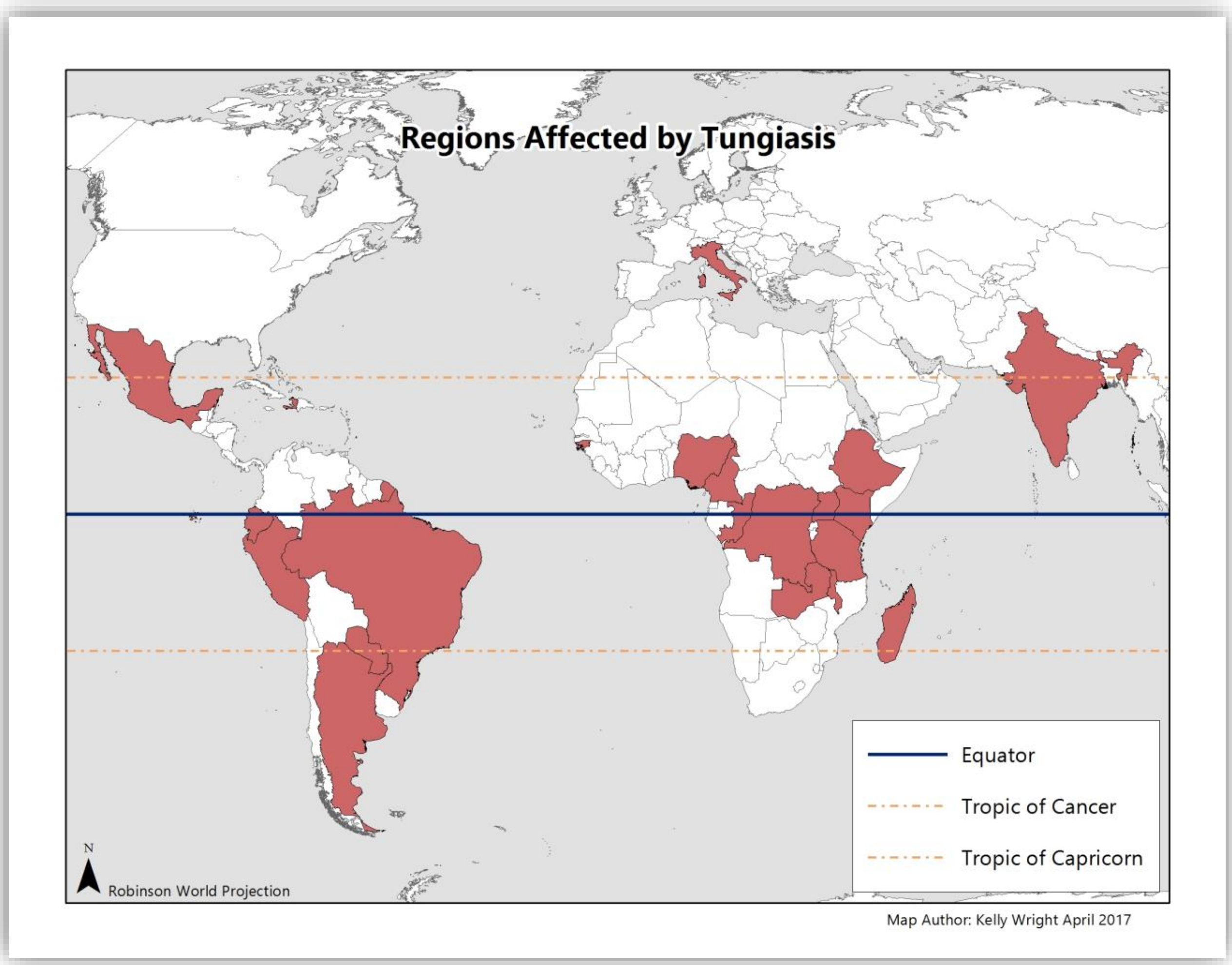


Figure 2 Countries Reporting Tungiasis

developmentally disabled. Despite its terrible social and economic costs and high morbidity, tungiasis is largely unheard of in developed countries and ignored in developing countries.

The mechanism for tungiasis is as follows: a gravid female flea burrows into the host's skin, feeding on the host's blood and remaining embedded until death weeks or months later. Its abdomen expands by a factor of 2000 over the next four to six weeks as it produces hundreds of eggs that are shed through its host's normal daily activity, especially walking (Pan American Health Organization 2014; Feldmeier et al. 2014; Heukelbach 2005a; Heukelbach 2005b). The presence of multiple fleas trigger a foreign-body immune response within the host's skin, prompting the immune system to release histamines causing inflammation and hardening of the skin surrounding the embedded flea. Over time, thick scales of toughened skin accumulate over the embedded fleas, generating ideal conditions for further infestation. When multiple fleas become encapsulated in the host's skin, this superinfestation is known as tungiasis (Heukelbach 2005b; Eisele et al. 2003; Nagy et al. 2007). In a singular infection, a flea's remains would be sloughed from the epidermis through normal tissue repair mechanisms, but in the case of superinfections, fleas decompose within the host's skin (Heukelbach 2005a; Feldmeier et al. 2010; Ugbomoiko, Ariza, and Heukelbach 2008). Intraepithelial abscesses form as the flea and its feces decompose, leaving the host at risk for secondary infections by bacteria such as *Staphylococcus sp.*, *Bacillus sp.*, *Streptococcus sp.* and *Clostridium sp*. In unvaccinated individuals, tetanus is also a threat (Feldmeier et al. 2002, Joseph et al. 2006; Kenya MOH 2014). Infestation is painful and disfiguring; the permanent loss of toenails is certain. If allowed to continue unchecked, a heavy *T. penetrans* infestation can lead to anemia, blood infection, gangrene, spontaneous auto-amputation of appendages, and rarely, death (Heukelbach 2005a; Joseph et al. 2006). Many people become unable to walk properly or at all, or are unable to use their hands to grip due to the pain and disfigurement associated with advanced tungiasis (Ugbomoiko, Ariza, and Heukelbach 2008; Feldmeier et al. 2014).

Surgical removal is the primary treatment method necessary for individuals already infested. The procedure to remove fleas and their remains is usually performed with a needle, a scalpel, or a razor blade. The dead outer layer of the epidermis, hardened by the body's immune response, is cut away to uncover the fleas with minimal damage to the lower layers of skin. Sedation or anesthesia may be considered an avoidable expense in poverty-stricken areas despite the extreme discomfort of surgical removal. While this physical intervention is a traumatic event leaving the patient injured, it is unavoidable once an infestation is continuous. Bacterial infection is a certainty unless purulent flea remains are removed. Moreover, unsanitary methods of removing infected material and flea remains with shared needles or razor blades may lead to transmission of blood-borne pathogens such as hepatitis B and C virus and HIV (Feldmeier et al. 2013).

Poverty is the single largest risk factor for tungiasis (Heukelbach 2005a). Related social and environmental factors associated with tungiasis include illiteracy, alcoholism, abbreviated or no education, lack of sustainable or safe access to water, poor sanitation and hygiene (UNICEF WASH strategies), low access to medical treatment, unsafe housing conditions, and high population density (Heukelbach 2005a). Feldmeier states, "Poverty is, in fact, such a constant characteristic of sand flea disease that the prevalence of tungiasis can be considered as a proxy for the economic development of a community" (Feldmeier et al. 2014). Multiple studies in Brazil found that the pervasiveness of dirt floors and cohabitation with livestock were key in contributing to the perpetuation of infestations, as were a lack of shoes, water for washing, and health education (Muehlen et al. 2006; Linardi et al. 2010; Eisele et al. 2003). In nearly all endemic areas, the lack of shoes due to poverty is one of the biggest risk factors. For unknown reasons, children and elderly people are at greatest risk for superinfestation of *T. penetrans* (Heukelbach 2005; Feldmeier et al. 2002). Afflicted children are likely to stop attending school due to painful lesions, insomnia from itching, and fear of persecution and ostracism (Njau et al. 2012; Heukelbach 2005; Feldmeier et al. 2002; Feldmeier et al. 2014).

This brief discussion of tungiasis, its mechanism of infestation, its environmental and social risk factors, and the social perils faced by those infested serves to point out that tungiasis does, in fact, meet all NTD classification criteria. This information also contributed to the development of the design of the CFEP app to serve as an infestation occurrence data collection tool. Currently, tungiasis is not classified as an NTD. Before detailing how tungiasis meets all of those criteria and is amenable to WHO Public Health interventions, the next section will briefly detail recently-published NTD (re)classification criteria.

1.1.3. NTD Classification Criteria

In 2012 the WHO published *Accelerating Work to Overcome the Global Impact of Neglected Tropical Diseases: A Roadmap for Implementation*, documenting official WHO strategies for the prevention, control, elimination, and eradication of NTDs. It justifies the adoption of Integrated Control (IC) as a management strategy and establishes specific targets and milestones for eradication, elimination, and control of NTDs by 2015 and 2020. It describes in detail each of the 17 (at the time of the 2012 publication) NTDs and defines target goals for each condition. Most importantly, it defines the five recommended strategies for the prevention, control, elimination, and eradication of NTDs, covered in detail in Section 1.2. (WHO 2012a). What it does not describe, however, is how to gain NTD classification for a previously unrecognized disease of neglect.

On 28 May 2016, the 69th World Health Assembly approved a resolution providing for the development of a systematic, technically driven process for the adoption of additional diseases as NTDs, citing as a reason "recognition of the fact that there are still many tropical, poverty-related diseases or conditions that remain neglected and for which advocacy, awareness, and research are required to develop better diagnostic methods, treatments, and control strategies" (WHO STAG 2016). Note that within these criteria the WHO refers to NTDs as "disease conditions." This distinction is important when considering the case of tungiasis, which in and of itself is not a disease, but rather a condition resulting from prolonged infestation of *T. penetrans* (Feldmeier et al. 2004). Likewise, most NTDs are the result of parasitic infection, so "disease conditions" is categorically appropriate. Table 2 lists the WHO STAG NTD classification criteria.

Table 2 WHO STAG NTD Classification Criteria

1	Disease conditions that disproportionately affect the poor, cause significant morbidity and mortality within those populations, including stigma and discrimination, justifying a global response
2	Disease conditions that primarily affect populations living in the tropics and sub-tropics
3	Disease conditions that are responsive to broad control by applying one or more of the five WHO public-health interventions adopted by the Department for Control of NTDs
4	Disease conditions that are relatively neglected in research and resource allocation

Criteria 1 requires that a disease disproportionately affect the poor and cause significant pain, suffering, and ostracism or stigma. Criteria 2 requires the disease primarily affect tropical areas. Criteria 3 requires that the disease be "immediately amenable to broad control, elimination or eradication by applying one or more of the five public health strategies adopted by the

Department for Control of NTDs" (WHO STAG 2016). This requirement, with its five possible sub-conditions, presents the biggest hurdle to overcome in terms of providing evidence. Criteria 4 requires that the disease be relatively neglected by research, and that new diagnostics, medicines, or control tools are not being regularly developed. These four NTD classification criteria are used to classify a disease in one of two categories: A or B. Diseases are placed in Category A if they fulfill all four criteria for NTD classification. They make up the list of NTDs included in large scale action for control, elimination, or eradication.

A disease is placed in Category B and given provisional status if it fulfills all but Criteria 3, since proving the efficacy of WHO public health strategies is complicated. The WHO STAG suggests that "stakeholders" and "national health authorities" should work toward determining feasible public health solutions, rather returning the burden to the petitioning nation (WHO STAG 2016). However, what "activities leading to advocacy by stakeholders" might be and what is meant by advocacy is unclear. If the result of that advocacy satisfies criteria 3, disease conditions may be upgraded to Category A alongside the other 18 NTDs. This was the case in 2016 with the adoption of mycetoma to the NTD list (WHO 2016c) and appears to be an acknowledgment that any official recognition from the WHO carries real consequence and weight with it. Indeed, stated motivation for the publication of the WHO roadmap is that, "there are other conditions that could be classified as NTDs for the purpose of advocacy to motivate action or research for the development of new solutions in low-resource settings" (WHO STAG 2016).

In the case of tungiasis, any WHO recognition would have real-world consequences vis-à-vis awareness and funding. Tungiasis definitely meets criteria 1, 2, and 4: it disproportionately affects the poor and causes significant morbidity within affected populations, it affects those primarily within the tropics, and it has been neglected in research and resource allocation (Ahadi Kenya Trust 2010; Arden 2008; Ariza et al. 2010; Dassoni et al. 2014; Feldmeier et al. 2004; 2009; 2002; 2014; 2006; 2013; Heukelbach 2005a; 2005b; Heukelbach et al. 2004; 2003; 2005; Hoeppli 1963; Karunamoorthi 2013; Lefebvre et al. 2011; Mazigo et al. 2012; MOH 2014; Mitchell and Stephany 2013; Muehlen et al 2006; Namuhani and Kiwanuka 2016; Njau et al. 2012; Ruttoh et al. 2012; Ugbomoiko et al. 2007; Winter et al. 2009). However, in order to satisfy criteria 3, it must be shown that tungiasis responds to one or more WHO Public Health Intervention strategies.

Section 1.1.3. described the NTD classification criteria established in 2016 for the adoption of additional diseases as NTDs. Section 1.1.4. introduces the WHO Pubic Health Intervention strategies and argues that tungiasis directly corresponds and is amenable to them, thus satisfying all four WHO STAG NTD classification criteria.

1.1.4. WHO Public Health Intervention Strategies

In the case of similar tropical diseases, a variety of treatment options—mechanical, chemical, and social—are revealed in public health literature. Many, if not all, of these treatment strategies align with WHO NTD classification Criteria 3. Table 3 lists the five public-health interventions currently utilized by the WHO to accelerate the prevention, control, elimination and eradication of NTDs. The following sections describe these interventions and their applicability to the case of tungiasis.

Table 3 WHO NTD Public Health Interventions

Preventive chemotherapy	the large-scale delivery of free and safe, single-dose, quality-assured medicines, either alone or in combination, at regular intervals to treat selected diseases
Innovative and intensified disease management	the management of diseases that are difficult to diagnose and treat and which can, in most cases, trigger severe clinical manifestations and complications
Vector control and pesticide management	the safe and judicious management of public-health pesticides to achieve vector control through integrated vector management
Safe drinking-water, basic sanitation and hygiene services, and education	the prioritization of improved sanitation combined with delivering preventive chemotherapy and health education to sustain reductions in the prevalence of many of these diseases
Zoonotic disease management	the application of veterinary sciences and interventions to protect and improve human health (also referred to as veterinary public-health)

1.1.4.1. Preventative Chemotherapy and Integrated Control

IC is the process of treating patients for more than one disease, parasite, or medical issue at one time, on a massive scale. PC, similar to MDA, is a mainstay of WHO NTD treatment strategies and IC. PC was first introduced in a 2006 WHO study of helminth (worm) infections and suggested the coordinated use of multiple antiparasitic drugs in control interventions (WHO 2006). The combined strategies of PC/MDA and IC were widely adopted after the WHO first convened a Global Partners Meeting in 2007, after which it was decided to scale up local control and elimination programs to the national level (WHO 2012a). Prior to the de facto adoption of IC in 2007, funding and research efforts focused at the local level. This focalization was a barrier to comprehensive health treatment since comorbidity is so common among NTDs.

Global health practitioners are beginning to recognize concrete economic savings and tangible successes with IC. One study argues that, "community-based drug delivery strategies not only provide a mechanism for engaging communities in active participation in public health efforts, but also a low-cost means to use the MDA mechanism to deliver intervention packages, including vitamin A, micronutrient supplementation, insecticide-treated [bed] nets or health education" (Lammie et al. 2006). One study in Nigeria revealed a ninefold increase in the use of insecticide-treated bed nets (ITN) after a single MDA round for schistosomiasis and lymphatic filariasis where bed nets were also distributed (Blackburn et al. 2006; Hotez, Raff et al. 2007). In another study, it was estimated that the "side effects" of one MDA/IC round included preventative anemia treatment for over 500,000 women who would become pregnant in the next year, and prevention of blindness for over 25,000 patients (Brady et al. 2006). Compared to nonintegrated programs, a drug package of four to six antiparasitics can be delivered at 26% to 47% the cost of traditional drug disbursement (Brady et al. 2006; Hotez, Molyneux et al. 2007).

Likewise, IC intervention packages in tungiasis-endemic areas could be modified to also include petroleum jelly, scalpels, and repellant for treatment and prevention of reinfestation. Many of these materials can be used for multiple disease conditions. Since confirmation of tungiasis infection is visual, tungiasis prevalence surveys can be performed while administering MDA during other public health control measures. Community-based organizations (CBOs) already perform surgical removal clinics for those afflicted by tungiasis; while performing these surgeries, it would be possible to administer MDA and other WHO interventions per the concept of IC. In this way, tungiasis is amenable to the WHO interventions of PC/MDA.

On the other hand, PC could be considered unsuitable for tungiasis; no single drug both eliminates embedded fleas *and* prevents reinfestation. (Since morbidity and mortality are primarily associated with the secondary bacterial infection that accompanies tungiasis, removal of purulent material via surgical means is necessary before chemotherapy.) That said, several medicines known to have some curative effects on tungiasis appear on the WHO Model List of

Essential Medicines (MLEM), a suggested list of medicines that the WHO considers crucial for global health (WHO 2015). These medicines, from antibiotics to vaccines, are so important that most large pharmaceutical companies donate them to developing nations and NGOs. Ivermectin has long been considered highly effective against tungiasis and appears both in the MLEM and in the list of major donations of medicine 2012 WHO *Accelerating Work to Overcome the Global Impact of NTDs* described in section 1.1.2., despite its efficacy being under debate after multiple double-blinded randomized controlled trials revealed conflicting results (Heukelbach et al. 2003; Heukelbach et al. 2004). A Malawi study supports the use of benzyl benzoate in treating tungiasis, noting spontaneous ejection of embedded fleas after four days (Mitchell and Stephany 2013). Studies in Brazil show promise in the twice-daily application of dimethicone (a major component of hand lotion and hair conditioner) to affected parts of the body, effectively suffocating the fleas (Feldmeier et al. 2006). A Madagascar study revealed that a four-week course of twice-daily application of the plant-based repellant Zanzarin® was shown to reverse tungiasis-associated clinical pathology almost completely (Thielecke et al. 2013; Thielecke et al. 2014; Feldmeier et al. 2006). Since the major components of Zanzarin are coconut oil, jojoba oil, and aloe vera, some communities can substitute those materials instead. Petroleum jelly and neem oil are also effective topical treatments and repellents. With the exception of Zanzarin (which was discontinued by its manufacturer), all these medications are on the WHO MLEM. The efficacy of these drugs and their presence on the MLEM indicate that tungiasis is amenable to PC per the WHO classification criteria.

1.1.4.2. Safe drinking-water, basic sanitation, and hygiene services

Safe drinking-water, basic sanitation and hygiene, and education together are mainstays of WHO NTD treatment strategies (Freeman et al. 2013). Access to safe, fresh water is a worldwide problem that affects billions of people. UNICEF, WHO, and other non-profit organizations (NPOs) work to ensure access, monitoring the number and condition of water access points in water-stressed areas. In a 2014 study that examined access to improved (piped) drinking water in SSA, rural households were 1.5 to 8 times less likely to have access to improved drinking water, 2 to 18 times less likely to have access to improved sanitation, and 2 to 8 times more likely to defecate in the open than the national average (Pullan et al. 2014). The UNICEF water, sanitation, and hygiene (WASH) program reports that 1 in 3 people worldwide does not use improved sanitation (UNICEF 2016b). In SSA, many rural residents use “leak tins,” or repurposed plastic containers that are used in some homes or schools as toilets; each receptacle must be carried to and emptied into a sanitary latrine daily. One study analyzed opportunities for and barriers to collaboration between disease control programs and stakeholders in WASH, identifying four goals for future collaboration: 1. Advocacy, policy, and communication, 2. Capacity building and training, 3. Mapping, data collection, and monitoring, and 4. Research (Freeman et al. 2013.) Web GIS applications like those proposed in this thesis fulfill these goals, providing a path for collaboration between different sectors working toward a common goal.

Tungiasis-specific WASH strategies include ensuring safe access to water for washing and drinking, addressing personal hygiene, managing human waste disposal, and the distribution of shoes and bedding. Equally essential is educating communities about the causes of the disease. In communities where tungiasis is endemic, sleeping shelters often provide better living conditions for pests than the humans that live in them (Feldmeier et al. 2014). In SSA and South America, families may live in a one- or two-room shack, with no waste facilities. Flooring is usually dirt, and doors and windows cannot be secured. Walls are not airtight; common building materials are mud, dung, and repurposed manmade materials. To prevent persistent tungiasis, public health officials suggest the pouring of concrete or plaster to cover exposed dirt floors and regular cleaning with water to prevent reinfestation (Ministry of Health 2014, Nagy et al. 2007). *T. penetrans* eggs hatch and mature in open soil, so sprinkling or spreading water on open soil can eliminate flea populations when done consistently. Unfortunately, water is not available for this preventative act in many communities—either the scarcity of water or the distance to the nearest access point makes the practice prohibitive. When possible, individuals are urged to house livestock outside the sleeping area to prevent continual infestation (Feldmeier et al. 2013).

Education cannot be underestimated in NTD management (Carter Center 2016; Brooker and Utzinger 2007; Kimani, Nyagero & Ikamari 2012) As mentioned earlier, educating communities about the cause and prevention of Guinea worm disease was as important as the provision of the technology to prevent future infection. In many communities in SSA, tungiasis is believed to be a curse (Kimani, Nyagero & Ikamari 2012). Some locals consider the infestation to be a result of sorcery brought upon a family accused of some perceived slight, and afflicted individuals are ostracized and shunned (Njau et al. 2012; Heukelbach 2005; Feldmeier et al. 2002; Feldmeier et al. 2014). Since tungiasis treatment requires medical volunteers spend extended periods of time with each victim as flea remains are removed, the opportunity for education is significant (Ariza et al. 2010). While administering medical aid, volunteers can explain that it is an insect that causes the illness, and it can be prevented. Since the burden of preventative care primarily falls on the women of the community (Winter et al. 2009), in educating these caregivers, the burden on women is lessened. Like the GWD success story earlier in this chapter, without education, the technology would not have had the same success. Having everyone on board is as crucial to NTD management as the provision of shoes and topical medications. This strategy also ties into the WHO public health initiatives of public education and improved sanitation.

1.1.4.3. Vector control and pesticide management

Chemical vector control, i.e. the application of pesticides, is another essential WHO NTD public health intervention and strategy (WHO 2010; WHO 2012a and 2012b; WHO 2016c). A major success in this case has been the distribution of ITNs in SSA mentioned in section 1.1.4.1. to combat the transmission of malaria from mosquitoes to humans (Blackburn et al. 2006; Hotez, Raff et al. 2007). In the case of tungiasis, a pesticide is sprayed within the home or sleeping shelter to reduce parasite load within the treated area, and open soil outside of shelters is treated to prevent reinfestation. Unfortunately, it is the dirt roads that now connect far-flung settlements that present the largest obstacle to true eradication—treating the vast expanse of roads is not feasible, especially when infected individuals shed flea eggs with every step. Because of this, pesticide treatment for *T. penetrans* focuses primarily on the home, where permethrin and deltamethrin are used as an insecticide and repellant (Klimpel et al. 2005; Pilger et al. 2008b). Malathion, an insecticide, significantly reduces the number of infestations when sprayed on the ground, and ivermectin, metrifonate, and thiabendazole are effective topical antiparasitic medications (Ngan 2016). Diatomaceous earth (DE), or the fossilized silica skeletons of ancient microscopic water-borne organisms called diatoms, has shown great promise as a non-toxic repellant and insecticide. DE has razor-sharp microscopic edges that cause hemorrhages in arthropods, leading to desiccation and death. Because it is not a pesticide, DE is safe for use around humans, livestock, and food crops. It is similar in appearance to talc or flour and is sprinkled on open soil in areas where fleas and other pests are present. DE is abundant and cheap; in many parts of the world DE can be mined from ancient sea beds, and the light dusting required for treating open areas means a little bit can go a long way. It never loses its efficacy and during the dry season does not need to be reapplied. DE can also be applied like a powder onto livestock. While vector control relies heavily on the type of pest being controlled (i.e. mosquito, guinea worm, kissing bug), *T. penetrans* prevalence does decline with regular treatments of pesticide, making it amenable to the WHO public health intervention concerning vector control.

1.1.4.4. Zoonotic disease management

It is also critical to address livestock as hosts or vectors for NTDs in addition to applying pesticides to areas frequented by humans. *T. penetrans* is not only a human parasite; in rural areas, pigs and cattle are common hosts, while cats, dogs, and rats are more common vectors in densely populated urban areas (Heukelbach et al. 2004; Ugbomoiko et al. 2007). Many communities that are worst afflicted by tungiasis are agriculturally dependent; individuals keep livestock—which are fiscally and socially valuable—inside their homes to protect their investment (Winter et al. 2009; Ugbomoikko et al. 2007). While most tungiasis-related scientific literature focuses on the humanitarian side, some studies have focused on the significance of animal vectors and suggest preemptive veterinary care of other reservoir animals such as rats, dogs, cats, pigs and goats (Heukelbach et al. 2004; Klimpel et al. 2005; Mutebi et al. 2015; Pilger et al. 2008; Ugbomoiko et al. 2007). Because so many other animals serve as hosts for *T. penetrans*, zoonotic disease management is essential and aligns closely with WHO public health interventions, further proving the case that tungiasis meets all criteria for NTD classification.

In conclusion, this discussion of NTD classification and criteria, tungiasis, and current intervention strategies emphasize the fitness of tungiasis to be classified as a NTD. It meets the criteria set forth by the WHO for NTD classification and is amenable to any of the five public health interventions outlined by the WHO. This information directly informed the motivation for the thesis project The thesis research objectives are described in detail in Section 1.2.

1.2. Thesis Project Objectives

This thesis project contains two key components that together provide local and global solutions for tungiasis management and eradication. The CFEP and Tungiasis eLibrary web mapping applications were developed to raise awareness about and actively combat tungiasis.

The CFEP application serves aid workers and NPOs developing strategies to manage tungiasis by providing a collective workspace in the form of a browser-based web GIS. It provides users with an opportunity to overlay 22 supporting data layers for spatial analysis, and enables the collection of georeferenced demographic and treatment data at the local level. It was designed to be a workspace for aid workers, aid organizations, and governments of afflicted regions, channeling data from the local to the regional. As aid workers visit an area to provide field surgery, shoes, and insecticides, they can use the CFEP's "Contribute Data" widget to record patient demographic data and document the use of pesticides in sleeping shelters and communal areas. NPOs and/or CBOs involved in tungiasis prevention and education are asked to draw their service areas on the map and provide contact information in order to facilitate cooperation between organizations and to reveal areas in greatest need of attention. The application prototype was published to the USC SSI Esri ArcGIS Online (AGOL) site as part of a course final project in early 2016, and the author presented the application at the 2016 Esri International Developer Summit and the American Association of Geographers 2016 annual meeting (Wright 2016a, 2016b).

At the global level, the Tungiasis eLibrary accepts data generated by users who "volunteer" it in the form of their own and others' tungiasis-related research to become the body of evidence needed to petition the WHO to reclassify tungiasis as a NTD. Literature and articles are georeferenced and added to the database, each point contributing to an authoritative spatial distribution of tungiasis which was until now not available. For example, early literature indicated *T. penetrans* had spread to India, Pakistan, and Asia (Gordon 1941; Hoeppli 1963; Hesse 1899; Bruce et al. 1942), but no contemporary scientific literature perpetuates these assertions. The eLibrary, by mapping locations of literature pertaining to tungiasis endemicity, occurrence, and research, generates a reliable, up-to-date spatial distribution of the condition that public health professionals sorely need. Because the application can accept attachments of any kind, there is no limit to the type of data that can be collected.

To further the global objective of providing the body of evidence, the eLibrary project involved the design, development, publishing, testing, and promotion of a geodatabase and web GIS application that displays an exhaustive collection of tungiasis-related journal articles on a web map. The main component of the application is a georeferenced collection of published, peer-reviewed journal articles that pertain to tungiasis or *T. penetrans*. Articles are categorized by "focus" (epidemiology, entomology, public health, veterinary, travel medicine, medicine, spatial data or general information). Researchers and authors submit their own or other authors published work to the database as VGI by linking to other sites or uploading original documents. Users are also invited to share unpublished work, conference proceedings, government and NGO whitepapers, and even spatial data itself to further research of tungiasis eradication. This collection of tungiasis-related literature and survey data help fulfill WHO criteria for NTD classification. Thus, member states who wish to petition the WHO for reclassification of tungiasis can append this "dossier" of information to their request in partial fulfillment of NTD-STAG criteria.

The project objectives created to fulfill the goals of the CFEP and Tungiasis eLibrary are listed in Table 4.

Table 4 Project Objectives

Curate an exhaustive, user-updatable collection of peer-reviewed scientific literature pertaining to tungiasis and *T. penetrans*.
Develop a global spatial distribution of tungiasis and *T. penetrans*
Develop, publish, test and promote purpose-built geodatabases for each application with VGI and supporting data • Local, on-the-ground epidemiological data collection • Literature collection to aid in global policy change
Develop a publicly accessible website for this study, documenting purpose, methodology, and application user workflows
Code and implement the web mapping applications using Esri ArcGIS Server, and Web AppBuilder to support the goals of this study
Demonstrate the unique fitness of web GIS for disease and vector management

1.3. Thesis Project Methodology

The following steps laid out in Figure 3 illustrate the high-level methodology framework used to design the CFEP and Tungiasis eLibrary applications to address the project objectives outlined above.

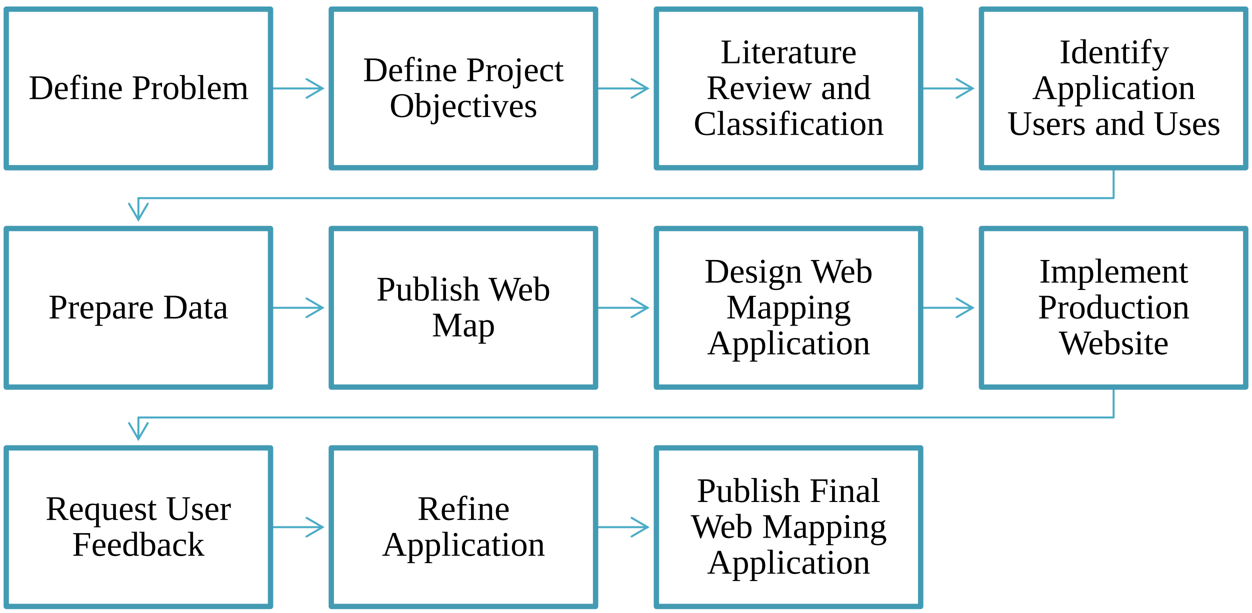


Figure 3 High-level Overview of Project Workflow

This high-level methodology workflow shows the progression of the thesis project from inception to implementation, but there are slight differences between the CFEP and eLibrary apps' methodologies. The research problem and objectives were refined first for the CFEP, namely, to demonstrate web GIS as a potential epidemiological tool by providing a collaborative workspace for aid workers and web GIS capabilities for all users. A thorough review of literature pertaining to tungiasis, *T. penetrans,* NTDs, and global public health was performed. Users and uses of the CFEP were identified, and the database structure was developed using Esri's ArcGIS Server (Esri 2017c). Supporting data layers were gathered from Kenya's Open Data Initiative (www.opendata.go.ke) and other NGO websites, and VGI datasets were created and edited using Esri's ArcMap (Esri 2017d). ArcMap was also used to prepare and publish Map and Feature Services to support an AGOL web map, where cartography and popup behaviors were modified, and Esri's Web AppBuilder (WAB) was used to design the interface for the CFEP web mapping application. The CFEP was embedded in a publicly-available website and presented at the 2016 Esri Developer Summit for feedback. and Tungiasis eLibrary were published to a publicly-available website. After testing the applications and getting feedback from public health and GIS professionals, the final web mapping applications were published

The CFEP had already been prototyped when the WHO NTD STAG released its roadmap to reclassification, so the informal tagging of articles led to the development of the Tungiasis eLibrary as a global tool to complement the local CFEP. The eLibrary's problem, objectives, users and uses were defined separately from the CFEP, but the remainder of the methodology remains the same. Each step in this methodology workflow is revisited throughout this thesis document, the structure of which is covered in the next section.

1.4. Structure of This Thesis

This chapter first presented the background and motivation for this project by describing the natural history, risk factors, and control of *Tunga penetrans.* It also introduced the NTD classification criteria, and detailed current tungiasis eradication strategies and how they align with WHO NTD public health interventions. Supported by this background information, the thesis research objectives were described and a high-level project methodology was outlined.

In addition to this introduction, this document contains six further chapters. Chapter 2 describes existing NTD databases/web mapping applications, introduces the concept of VGI, its advantages, and drawbacks, and briefly discusses participatory GIS and popular epidemiology, presenting advantages and drawbacks of VGI-derived data. Section 2.3 details the article selection methodology for the population of the Tungiasis eLibrary. Chapter 3 describes the technology used to produce the two applications, discussing software selection, back-end database architecture, and presents entity-relationship diagrams (also known as ERDs) for both applications. Chapter 4 contains detailed information about the applications’ development and describes the data layers within each app. Chapter 5 discusses testing the apps and provides a meta-analysis of the collected articles. Chapter 6 describes the thesis project results including widgets and workflows, and Chapter 7 draws conclusions about the project and suggests future work.

Chapter 2 Related Work and Literature Review

Recent research in the public health sector acknowledges the power of open data in combatting several poverty-related diseases and conditions. Because GIS technology has so rapidly advanced in the last decade, many epidemiologic maps with varying levels of interaction have come and gone with little lasting effect, but each new iteration builds on the successes of previous applications. There is a clear need for mapping in the control of NTDs; of most interest to scientists and policy-makers are maps of *prevalence* and maps of *distribution*. The distinction between the two is one of semantics but critically important. Species and disease distribution maps indicate areas where a parasite or disease is known to exist, while prevalence maps indicate the intensity of infection within a population, usually presented as a percentage. Both are of equal importance to public health organizations and scientists, and locating data for either is problematic. Static maps of these variables are obsolete almost as soon as they are printed, so a dynamic web map of prevalence would be of great use to researchers, especially one storing georeferenced prevalence studies in the scientific literature *and* “gray” literature (conference proceedings or other extra-academic organizational publications), white papers, or old and unpublished data (Jovani and Tella 2006). To the author’s knowledge, a VGI-based database developed for WHO disease reclassification has never existed, nor has a web GIS been proposed to house both socioeconomic and epidemiologic data collected by aid workers and georeferenced, peer-reviewed scientific literature. Additionally, the provision of fundamental GIS workflows to multiple organizations battling the same disease across great distances is a very recent capability thanks in large part to Esri widgets enabled through web GIS and an organizational account.

Because no examples of this particular combination of web GIS, VGI, and advocacy yet exist, the related work discussed in this chapter examines existing web mapping applications that have been tailored to specific NTDs. Section 2.1 reviews web mapping applications containing one or more comparable components to the CFEP and eLibrary and compares the apps to develop a set of best practices for functionality development. Section 2.2 introduces the concepts of VGI and popular epidemiology, and examines the growing ubiquity of mobile devices and smartphones since this is highly relevant to the future success of the CFEP.

2.1. Existing NTD Mapping Databases

The following sections will review existing web mapping applications that store and distribute NTD data and prevalence studies. A primary function for all these databases is to produce paper maps of distribution, prevalence, endemicity, and risk. The NTD Mapping Tool, (NTD MT), Global Neglected Tropical Disease database (GNTD), Global Atlas of Helminth Infections (GAHI), and the Global Atlas of Trachoma (GAT) are reviewed and compared in the following sections. Table 5 lists the reviewed NTD mapping resources, their GIS capabilities, and the software used to develop each.

Table 5 NTD Mapping Resources

Mapping Resource	GIS Capabilities	Software Resources	Website
The NTD Mapping Tool	Overlay with Reorder Edit Feature Symbology Data Download: SHP Basemap Gallery, Print	Version 2.0: Leaflet Version3.0: ArcGIS API for JavaScript	www.ntdmap.org/
Global NTD database	Data Download: Excel	Unknown	www.gntd.org/
Global Atlas of Helminth Infections	Data Query and Filter Overlay with Reorder Attribute Table Basemap Gallery, Print	Esri Web AppBuilder	www.thiswormyworld.org/

Global Atlas of Trachoma	Overlay, No Reorder	Leaflet, technical documentation N/A	www.trachomaatlas.org/

2.1.1. The NTD Mapping Tool

A group of researchers affiliated with the Task Force for Global Health at Emory University in Atlanta designed the NTD Mapping Tool in 2013 with the goal of providing a single tool with functionalities particularly useful for the planning and evaluation of NTD programs (Flueckiger et al. 2015). Following its latest application update (December 2016), the NTD MT housed at http://www.ntdmap.org/ is a web GIS that dynamically links data from GAHI, GAT, the International Consortium for Trachoma Control, the Expanded Special Programme for Elimination of NTDs (ESPEN), Imperial College London, and the Barcelona Institute for Public Health with the goal of visualizing the geographical distribution and treatment statuses of seven NTDs. Additionally, the application includes Water and Sanitation datasets in the form of first-level administrative unit (FLAU) choropleth maps representing access to safe drinking water, adequate sanitation facilities, and open defecation for nearly all of SSA. As well as the project's objective of cartographic visualization, the NTD MT also aims to identify priority areas for MDA and areas where IC can impact multiple diseases of poverty. Table 6 details the NTD MT Project Objectives.

Table 6 NTD Mapping Tool Objectives

To visualize the geographical distribution of NTDs
To identify priority areas requiring mass drug administration
To identify areas for co-implementation of control activities
To visually explore the relationship between NTDs and water and sanitation
To track programs in NTD control

The CFEP and Tungiasis eLibrary apps largely meet these NTD MT project objectives. The eLibrary fulfills the first objective by creating, in effect, a global *distribution* map for tungiasis by displaying data points representing georeferenced volunteered literature or data plotted on a world map. This visualization makes it readily evident that *priority areas* are tropical regions in Africa and South America, and the uploaded literature specifies other disease potentials in endemic areas and suggests inexpensive treatments or medicines that can be distributed via *integrated control*. The CFEP permits overlay of water and sanitation data with disease endemicity layers *and* a layer in which aid organizations can draw service area boundaries, literally identifying areas that are not being actively monitored for repeat *T. penetrans* infestation. While the eLibrary does not contain additional datasets depicting *water and sanitation* in developing nations, the CFEP does contain WASH data within Kenya, and the link between tungiasis and WASH is widely accepted (WHO no date). Lastly, the CFEP provides the capability to map service areas and contact information for *organizations and programs* working toward tungiasis eradication. While the eLibrary's function was influenced by the NTD MT, it was not until the eLibrary was already under construction that the NTD MT was discovered by the author; it is a testament to the total applicability of GIS to epidemiology and a shared technological framework that the application designs are so similar.

There were other aspects of the project that were critical in the development of the Tungiasis eLibrary. A good portion of the initial NTD MT study was dedicated to an analysis of existing mapping applications and a needs assessment among staff from NTD control programs (Avia-GIS 2012). The results of the survey revealed that participants prioritized the ability to overlay map layers, combine data sources, navigate to specific areas, download data, and draw tables. Fortunately, these needs are easily addressed when using Esri's ArcGIS suite of software and applications. The ability to pan, zoom, and search for locations using Esri's World Geocoder is included in all Esri web mapping application development environments. Esri WAB widgets empower eLibrary users to browse the collection of articles by country, produce charts of the collected data, and select, export and download data.

The NTD MT team released a new application, version 3, in December 2016 while this manuscript was being finalized. Because the differences between versions 2.0 and 3.0 are relevant to the discussion of the NTD MT and development of the design of the Tungiasis eLibrary, both versions 2.0 and 3.0 will be examined.

2.1.1.1. NTD Mapping Tool application version 2.0

The pre-2017 NTD MT utilized Esri's database management platform to link Structured Query Language (SQL) databases from multiple partners (e.g. GAHI described above). The service was hosted on an Esri server pushing the information to the project's website as layers. The website encompassed a full-screen web mapping application with subtle base cartography and easily-browsed layers, that was intuitive to use. Leaflet, a JavaScript library for interactive maps, was used to develop the visual interface, which features light gray cartography and bright colors symbolizing data. Point layers are symbolized using colored point features while some data is visualized at various administrative levels using choropleth maps. Figure 4 shows the NTD Mapping Tool interface.

The task force selected QGIS (formerly Quantum GIS) as the GIS infrastructure so that anyone could freely download the open source GIS software to perform offline GIS capabilities (http://www.qgis.org). The goal of the project was "to provide a single tool with functionalities that are particularly useful for the planning and evaluation of NTD programs" (Flueckiger et al. 2015). The NTD MT is one of the more robust applications reviewed here. Version 2.0 was

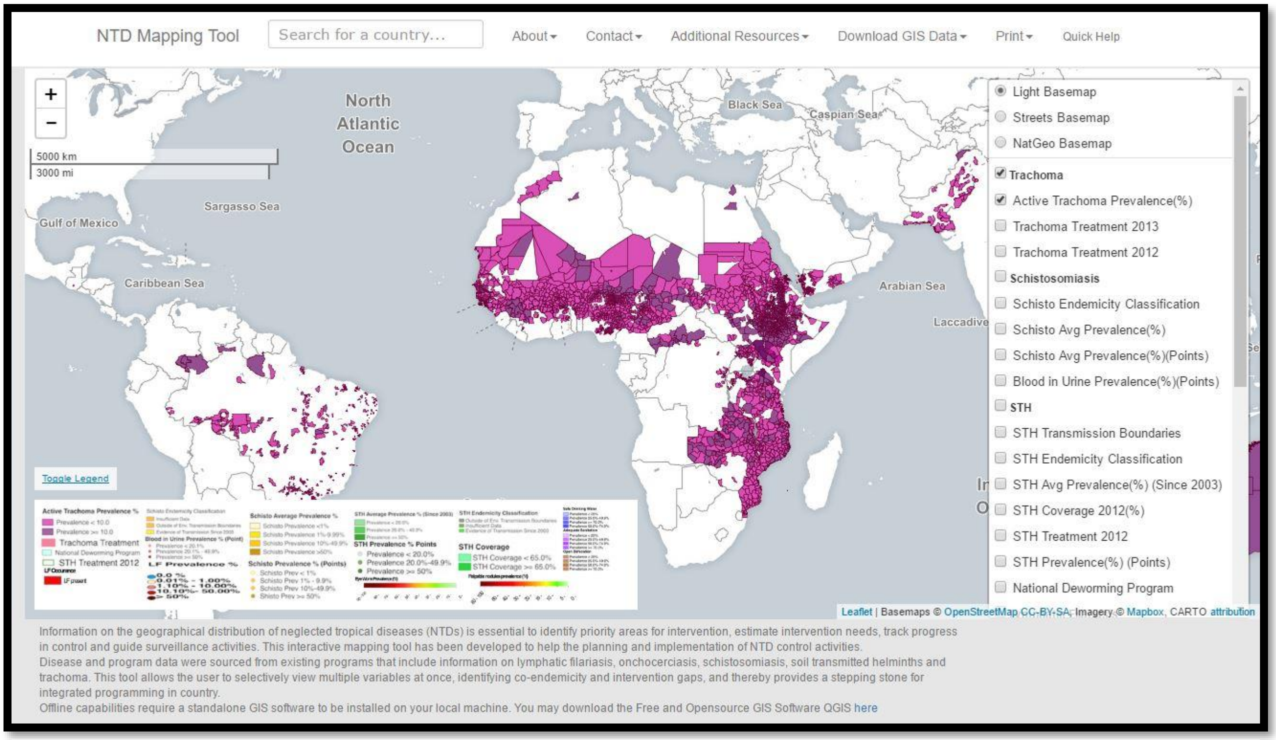


Figure 4 The NTD Mapping Tool Interface, Version 2.0 Interface

superior to other NTD web mapping applications because it allowed users to download derived GIS data in KML, shapefiles, and QGIS map package formats. For unknown reasons, this function changed dramatically between versions 2.0 and 3.0, and currently the data is available in one format per layer, only as shapefiles, and rasters.

While the application was state-of-the-art at its release in 2013, there were several drawbacks to version 2.0. From a cartographic perspective, the map elements were not well-placed; the scale bar covered much of the mapped area and was awkwardly situated beneath the zoom +/- buttons. A major failing of the application was its legend which could not be resized and displayed the key for every layer in the application regardless of whether the layer was turned on. This necessitated the use of an exceptionally small font; the legend was therefore so text-dense and hard to read that it discouraged further exploration. Similarly, the layer list covered a large part of the mapped area and was not collapsible. A large amount of screen real estate was lost to the fine print at the bottom of the map and at the top of the map where drop-down menus are located. Amounting to graphics, these map features were not responsive to a change in screen size or pinch-and-zoom on a mobile device.

Nevertheless, the NTD MT had some excellent functionality and add-ons. One of the NTD MT's greatest assets was the Quick Help Document, illustrated in Figure 5. The Quick Help Document, a single image with markup describing the app's features, is incredibly informative despite its simplicity. It reduces user need to access the full user guide under the About menu, a fourteen-page portable document format file (PDF) entitled *A User Guide for Online and Offline Use of the NTD Mapping Tool 2.0* (NTD Mapper 2014). Also in the About

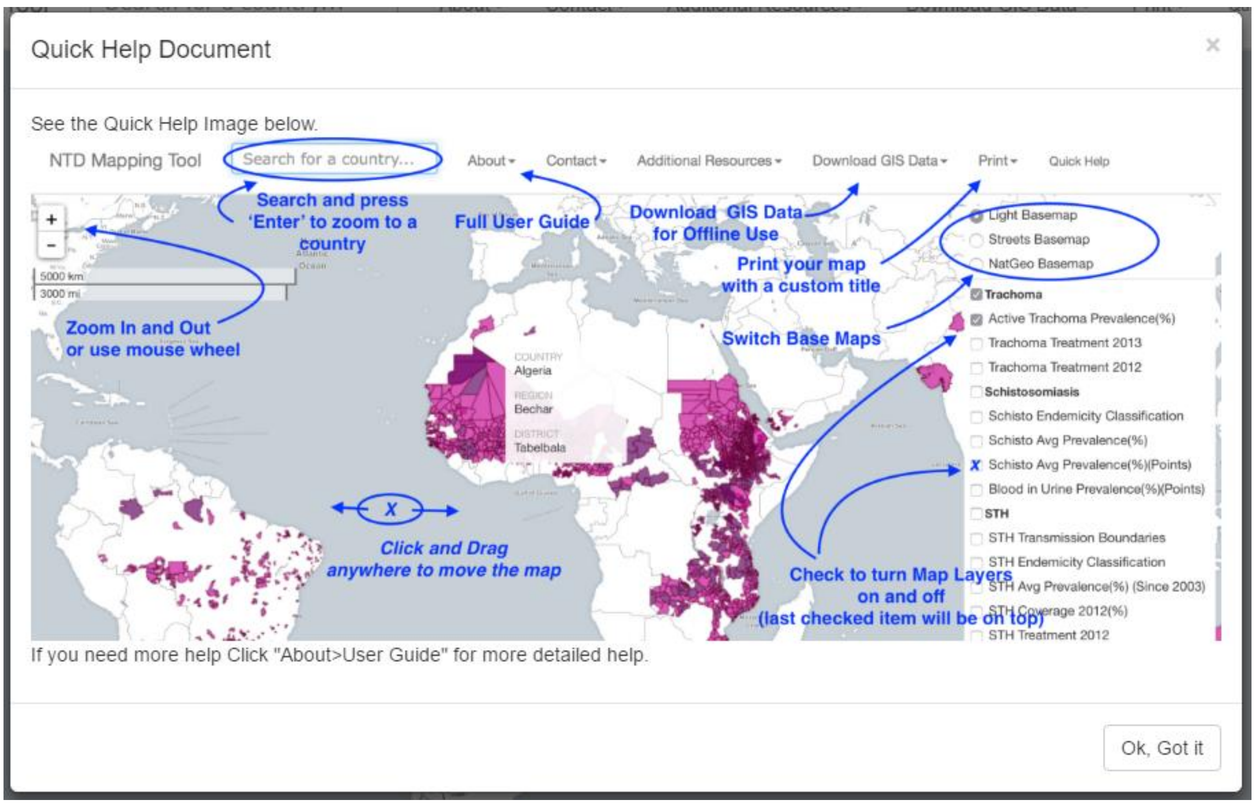


Figure 5 NTD Mapping Tool Quick Help Document, Version 2.0 Interface

menu is a pdf "postcard" for use in promotional or communications products. This low-text, engaging brochure described the NTD MT, listed the URL for the application, and detailed improvements in version 2.0. These user-friendly additions to the otherwise austere application informed both the CFEP and Tungiasis eLibrary final websites and web mapping applications. In addition to a detailed Help widget and How-To tab on the website, a jpeg image of the app with markup is included, like the NTD MT's Quick Help Document.

2.1.1.2. NTD Mapping Tool application version 3.0

Version 3.0 of the NTD MT is visually very different from its predecessor. Instead of the unremarkable light gray cartography of version 2.0 common to the Leaflet JS library, the basemap and service credits are unmistakably Esri in origin (starting, obviously, with the service credits in the lower right). For users familiar with Esri iconography and basemaps, it is apparent that this application was designed using either the Esri ArcGIS application programming interface (API) for JavaScript or WAB. Figure 6 shows the updated interface of version 3.0.

Examining the hyper-text markup language (HTML), or "code" of the application reveals that version 3.0 was indeed designed using ArcGIS for JavaScript, the JQuery JavaScript library, and Bootstrap framework. Leaflet JS is no longer utilized. New browser support, including support for Chrome for Android and Safari for iOS, is included. These improvements produce a responsive web mapping application with inbuilt GIS operations managed using the ArcGIS API for JavaScript, which also enables map and popup customization beyond what is available within Esri's out-of-box WAB. Application improvements also include popups in the form of an Identify widget, the ability to edit feature symbology, a modifiable layer display order, and the ability to navigate by typing a country name into a search box.

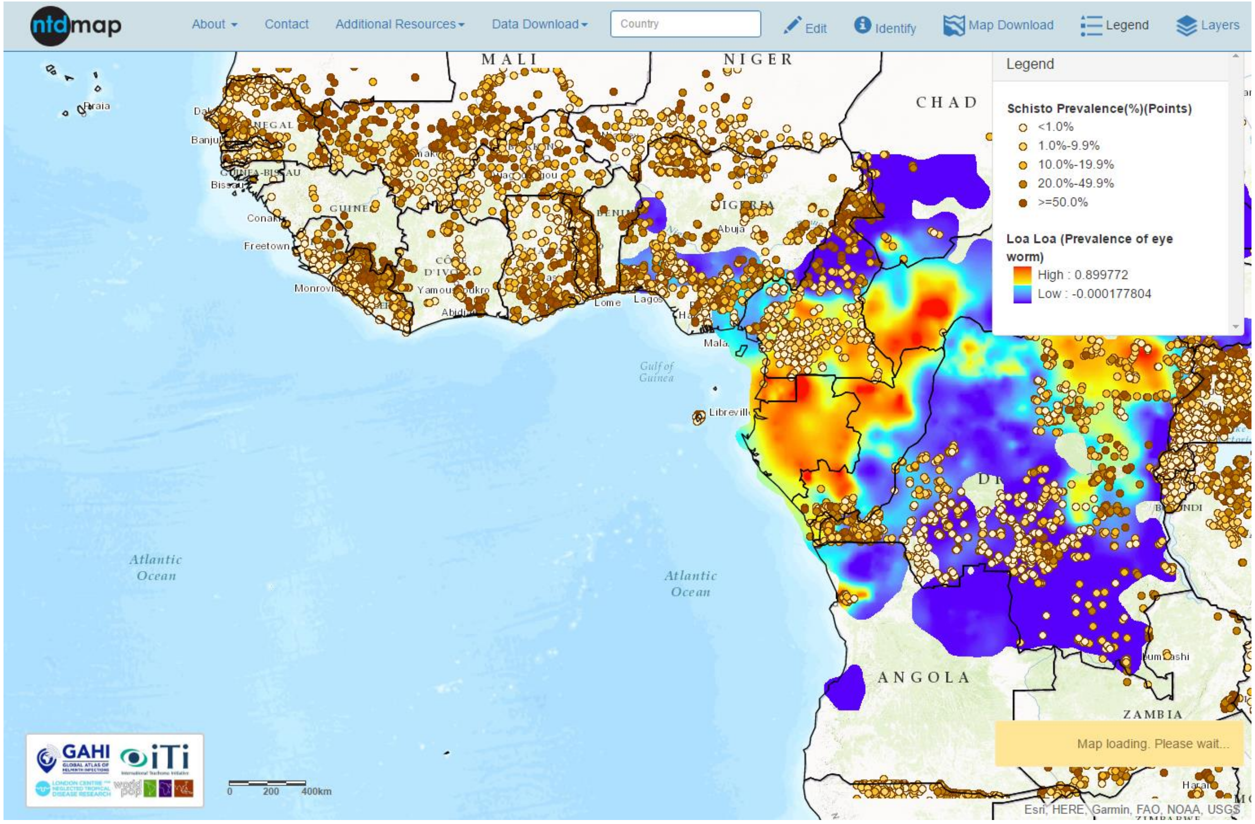


Figure 6 The NTD Mapping Tool Version 3.0 Interface

The NTD MT claims to be newly functional offline by downloading layers for use in desktop GIS software suites, but the irony is that the data are available in *fewer* formats than in the previous version. In both versions maps created in the app can be printed or downloaded in multiple graphic formats, but not as GIS data packages for offline use (layers must be downloaded individually). Detailed technical documentation about the underlying framework of the NTD MT is not available for version 3.0. QGIS is no longer mentioned on the app website or in its documentation. Surprisingly, the capability to allow users to add their own data did not appear in version 3.0 despite the indication in the original research that future releases would include that ability (Flueckiger et al. 2015).

The application references data provided by disease-specific aid organizations, presenting the disparate sources as layers that can be overlaid for comparison. Data layers for trachoma, schistosomiasis, soil-transmitted helminths, lymphatic filariasis, loa loa, onchocerciasis, and yaws are presented in a responsive layer list that resizes based on content, and the legend automatically resizes depending on the layers checked in the layer list. Additional data layers include WASH data, population density, urbanization, political boundaries at multiple administrative levels and model-based geostatistical analysis (for loa loa only). Detailed metadata is housed under the "About the Data" subsection of the "About" dropdown of version 3.0. Called "Map Methodology," this 5-page pdf describes each layer in the dataset in detail and gives references for all data layers. Accompanying the methodology is a link to the original 2015 project manuscript. Instead of the graphical user guide earlier admired in version 2.0, a single 4-page pdf (reduced from 14 pages in version 2.0) "User Guide" is located under the "About NTD Map" subsection of the "About" dropdown. The complementary single-page "Project Summary" provides background for the project, details project objectives, and includes hyperlinks to key partners and collaborators' organizational websites.

Both versions of the NTD MT informed the development of the design of the CFEP and eLibrary apps, justified the author's selection of WAB, providing a transparent user experience, and visualizing the data globally. The next section discusses the GNTD, the second of four NTD mapping applications reviewed in the related work section.

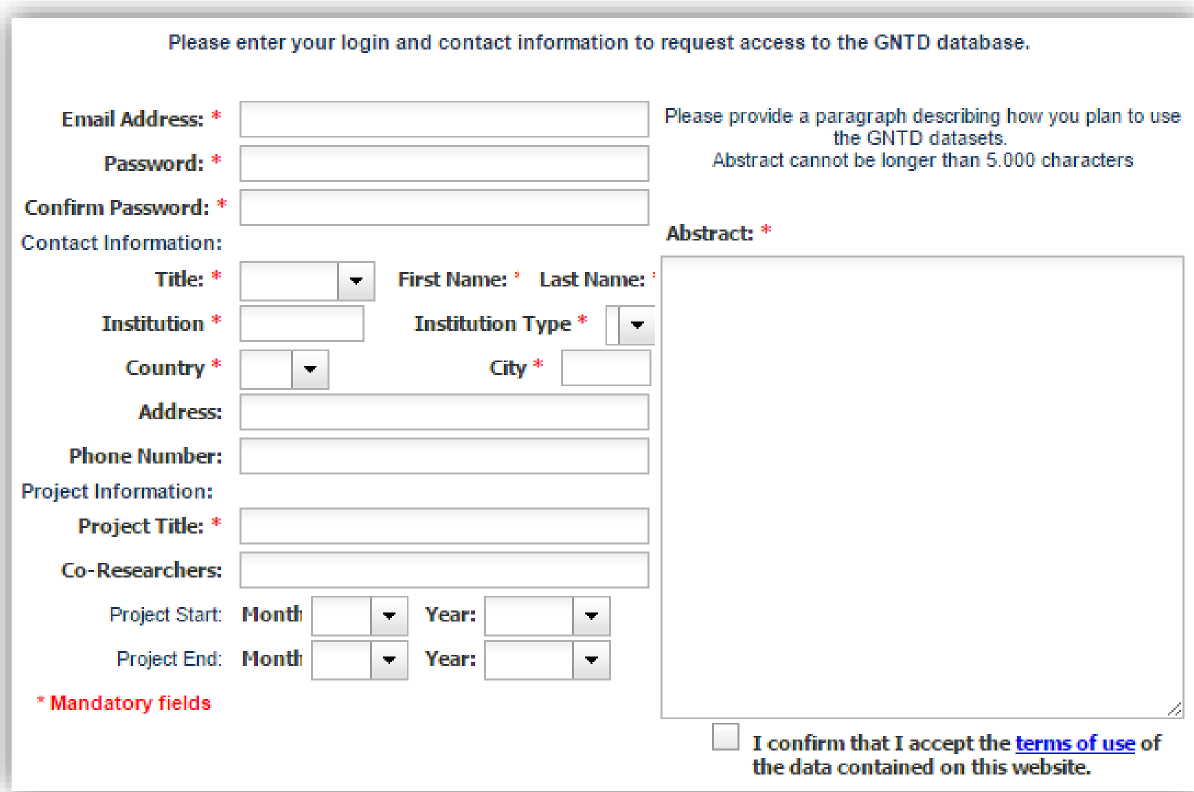
2.1.2. Global Neglected Tropical Disease Database

The GNTD database was developed as part of a joint effort of the Swiss Tropical and Public Health Institute, the University of Copenhagen, Denmark, and the University of Zambia (Hürlimann et al. 2011). The GNTD was a result of a multidisciplinary project exploring schistosomiasis transmission and began as a data repository for location-specific schistosomiasis prevalence surveys in SSA. Schistosomiasis, a NTD caused by a parasitic flatworm, was selected as the proof-of-concept NTD for the project and at publication, more than 12,000 survey locations had been recorded. The study's conclusion and future work section suggested end users should be able to upload community-sourced data to a SQL database using smart phones in future releases (Hürlimann et al. 2011). This supported the decision to design the CFEP building upon volunteered and community-sourced data.

In the GNTD, data are stored and managed in a MySQL relational database with a web interface built using hypertext preprocessor (PHP) (Hürlimann et al. 2011). Users can search the database by country, document category, disease, and journal. This classification and filter system was tailored to the Tungiasis eLibrary; since VGI (in the form of articles) is classified by document category, primary and secondary focus, country of study and country of author, pre-set SQL queries enable users to quickly locate articles of interest.

The GNTD user interface heavily informed the premise of this thesis project, providing examples of app functionality to mimic as well as pitfalls to avoid. For example, a large takeaway from the GNTD was its detailed data selection methodology. This provided a succinct workflow to modify to systematically review articles during extensive background research and data (article) collection and curation. The article selection process is reviewed in detail in Section 5.3 of this thesis along with a meta-analysis of collected articles.

The GNTD is not a mapping application per se, but it provides one model for vetting users that could be applied to this web GIS thesis project. Early in the project's development, requiring users to register to volunteer data to the CFEP and eLibrary apps was considered, mostly to prevent vandalism and protect patient data privacy. The GNTD has an extensive vetting process just to access its data. Figure 7 shows a screenshot of the registration form for the GNTD database. The form is cumbersome enough to ensure that those who do complete the process must have a sincere desire to do so. It includes a Terms and Conditions checkbox and requests an abstract of up to 5,000 characters about how the datasets will be used.


Please enter your login and contact information to request access to the GNTD database.

Email Address: *
Password: *
Confirm Password: *
Contact Information:
Title: * First Name: * Last Name: *
Institution * Institution Type *
Country * City *
Address:
Phone Number:
Project Information:
Project Title: *
Co-Researchers:
Project Start: Month Year:
Project End: Month Year:
* Mandatory fields

Please provide a paragraph describing how you plan to use the GNTD datasets.
Abstract cannot be longer than 5.000 characters
Abstract: *
I confirm that I accept the terms of use of the data contained on this website.

Figure 7 Form to Request Access to the Global Neglected Tropical Diseases Database

Unfortunately, while the form is exhaustive, it is also off-putting. It takes a great deal of time to register, and despite the project claiming to be "open-access," one cannot access the tool without completing registration. Also, some users may never gain access to the database. Despite completing the entire registration request, the author never heard back from the GNTD administrators and was never able to access to the database. The complexity of requiring registration informed the decision that the Tungiasis eLibrary be freely available to any user, regardless of registration status. Open access also prevents the need for a figurative middleman granting access to some and denying others. In this project, the GNTD informed design decisions to allow users to freely browse, download, and contribute data, while still considering basic safeguards against user mischief such as guarding against deletion of data.

2.1.3. Global Atlas of Helminth Infections (GAHI)

Like the GNTD, the GAHI is an example of a database dedicated to gathering volunteered parasite prevalence estimates at the local level. A collaborative effort between WHO and the University of Oxford launched this initiative aimed at collating available parasitic worm survey data as both a database and graphical tool (GAHI 2016). Initially designed with the production of paper maps in mind, the GAHI is housed at http://www.thiswormyworld.org/ and is an open-access, global information resource about the spatial distribution of helminth (parasitic worm) infections. The purpose of the website and its static maps is to display the prevalence and distribution of soil-transmitted helminth (STH) infections, lymphatic filariasis (LF), or schistosomiasis, all parasitic NTDs afflicting people living in poverty in developing nations. Like the NTD MT, it was only after returning to the websites while writing this manuscript that a change was detected, and like the NTD MT comparisons between the earlier and later versions are germane to this thesis project.

2.1.3.1. GAHI 2016 – static maps

Early research of the GAHI for inclusion in this analysis left much to be desired. In mid-2016, the GAHI utilized data from published LF, STH and schistosomiasis surveys to create three static map types at the second administrative, or district, level. Despite later-discussed upgrades to the GAHI website, these maps can still be browsed as of January 2017. While the data for these maps are constantly updated, the maps themselves are not dynamic. Map types include “Survey Data,” visualizing infection prevalence, while the “Predictive Risk” map type displays areas where infection probabilities warrant MDA per WHO thresholds. The “Control Planning Map” (no longer available as of January 2017) highlights areas of <no data>, indicating areas where further survey information is required to confirm the presence or absence of a vector species (Brooker, Hotez, and Bundy 2010). The “Water Supply and Sanitation Coverage” map type (potentially new as of 2017) maps statistics of open defecation, water sanitation, and use of improved drinking water sources. The maps can be browsed using drop-down menus to choose the country of interest, or the user can browse by the aforementioned map types, worm species, or geographic region. The number of derived maps is overwhelming (959 as of January 2017) and navigated by web pages of tiles rather than graphical layers on a map. The maps can be downloaded in PDF and PNG file formats. GAHI cartography is geared toward utility and homogeneity; It is worth noting that the intended users are scientists and public health officials who might find this homogeneity desirable when comparing multiple countries’ or epochs’ maps at once. Considering the sheer wealth of prevalence data that is available and the flexibility of interactive (clickable) web mapping applications in recent years, it was surprising to discover use of low-tech maps used for the project. Figures 8 and 9 show examples of 2016 and 2017 static maps produced with the GAHI application. Note the differences in cartography between the 2016 and 2017 versions.

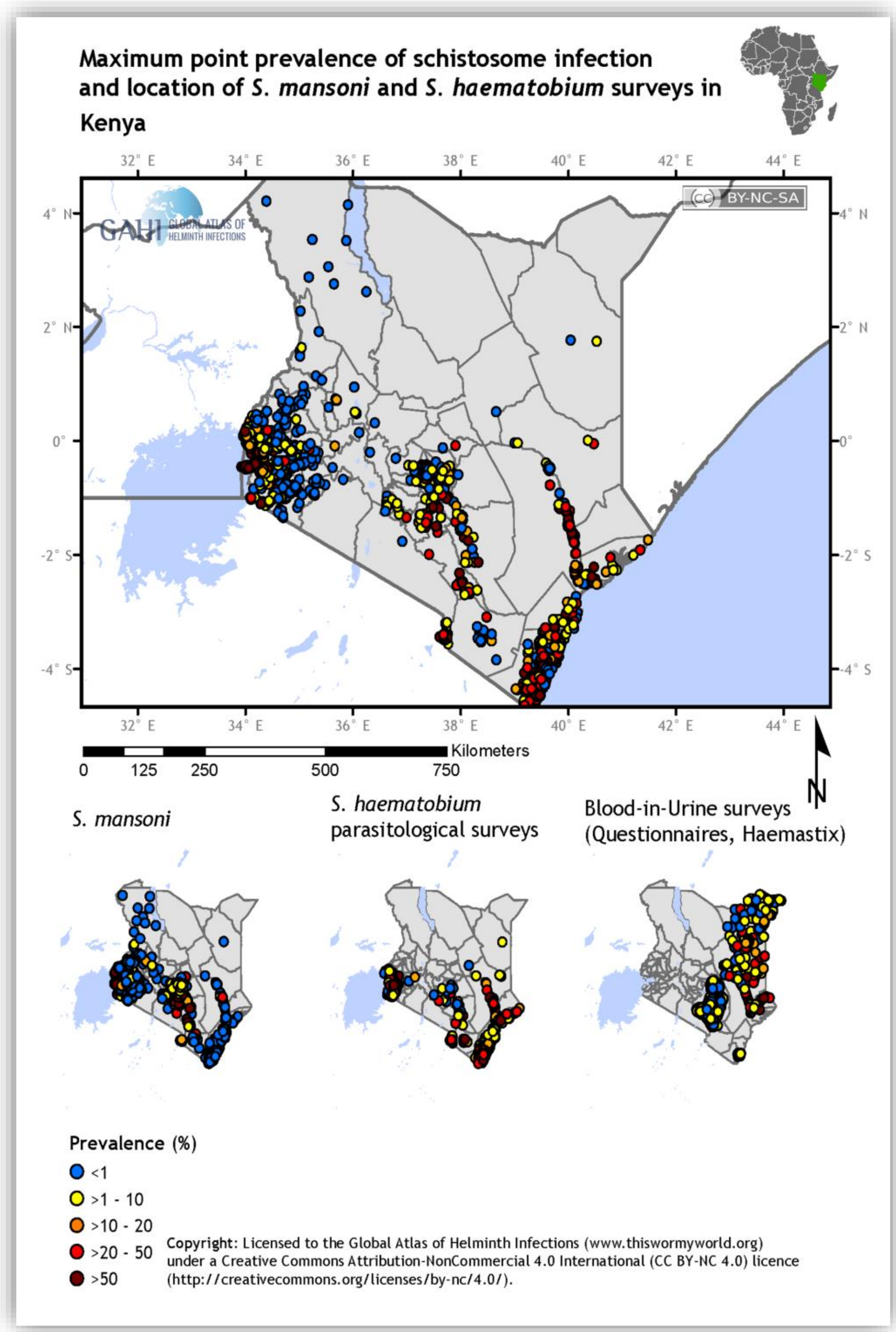


Figure 8 Global Atlas of Helminth Infections Prevalence Map Example (2016)

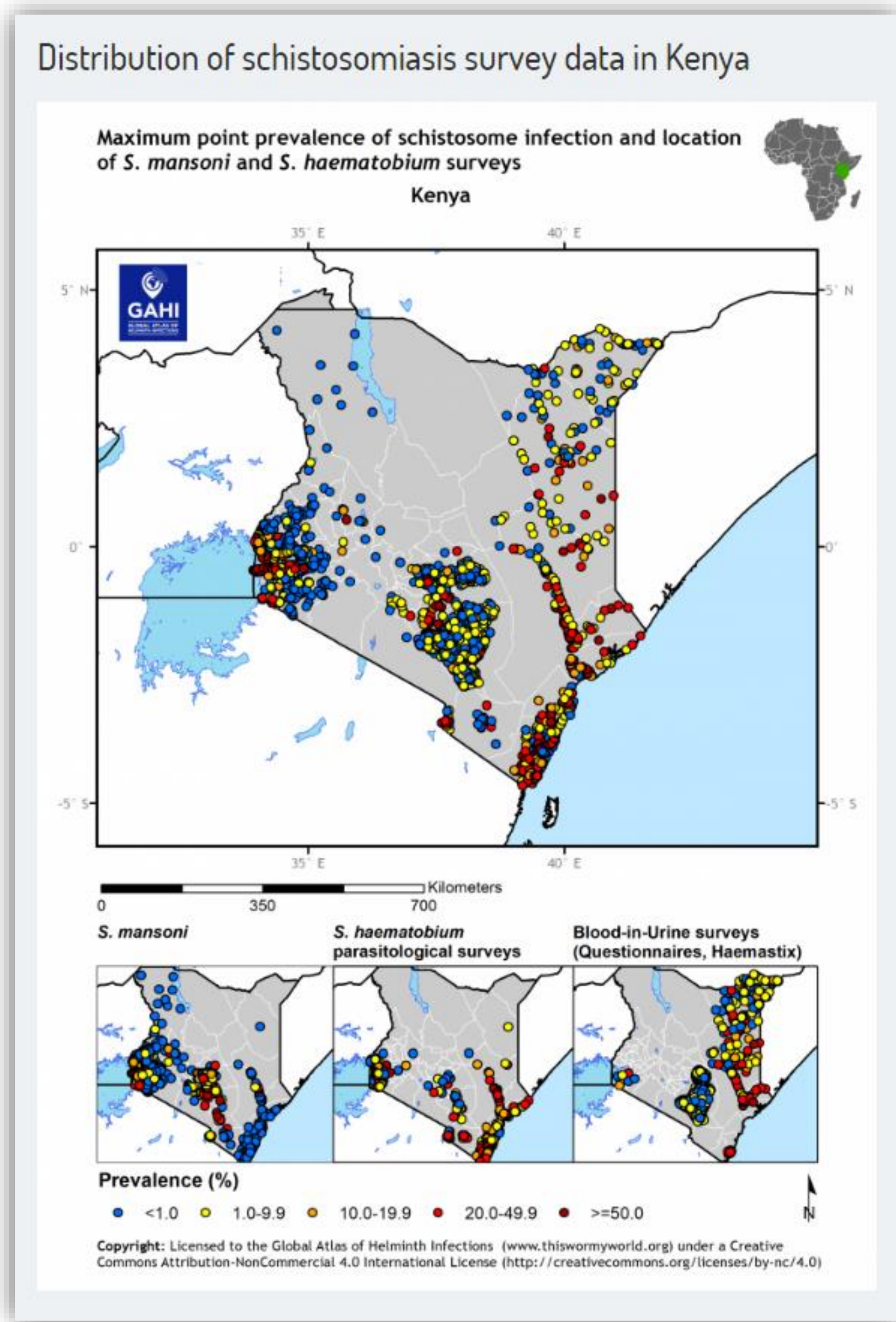


Figure 9 Global Atlas of Helminth Infections Prevalence Map Example (2017)

2.1.3.2. GAHI 2017 – Web AppBuilder version

The 2017 version of the GAHI was constructed, like the CFEP and eLibrary, using Esri's WAB. On the GAHI's website, two Esri WAB apps linked to the "Create a Map" page significantly influenced this thesis project. These apps did not exist prior to late 2016 and were not encountered by the author until the late stages of writing the manuscript. Each app displays NTD distribution data and permits GIS workflows. One of the apps, detailing LF distribution and prediction, is extremely bright, visualizing its default areal data in bright reds and blues. The other, detailing STH and schistosomiasis, uses shades of a bluish green for its polygons; both maps use Esri's standard terrain basemap. These dynamic web map applications display all the data on global maps that can be panned, zoomed, overlaid (with reorder), and masked for map export, and include several widgets performing both map functions and data interactions. Of all the reviewed apps in the Related Work section, these two contain the most analogous functionality to the CFEP and eLibrary applications—unsurprising since their development age and background software architecture are so similar.

Specifically, the GAHI's Query Widget has been tailored to filter surveys by country. The Tungiasis eLibrary was also customized to use the Query Widget in this manner, enabling users to easily browse the uploaded literature by topic, source, author, and country, among other attributes. The GAHI attribute tables for visible layers are also available for the user to view, a functionality that was not included on any other application reviewed for this project. The GAHI About Widget describes the project and the data contained in the application. Figure 10 shows the user interface for the GAHI STH/Schistosomiasis mapping application (https://lshtm.maps.arcgis.com/apps/webappviewer/index.html?id=2e1bc70731114537a8504e3260b6fbc0).

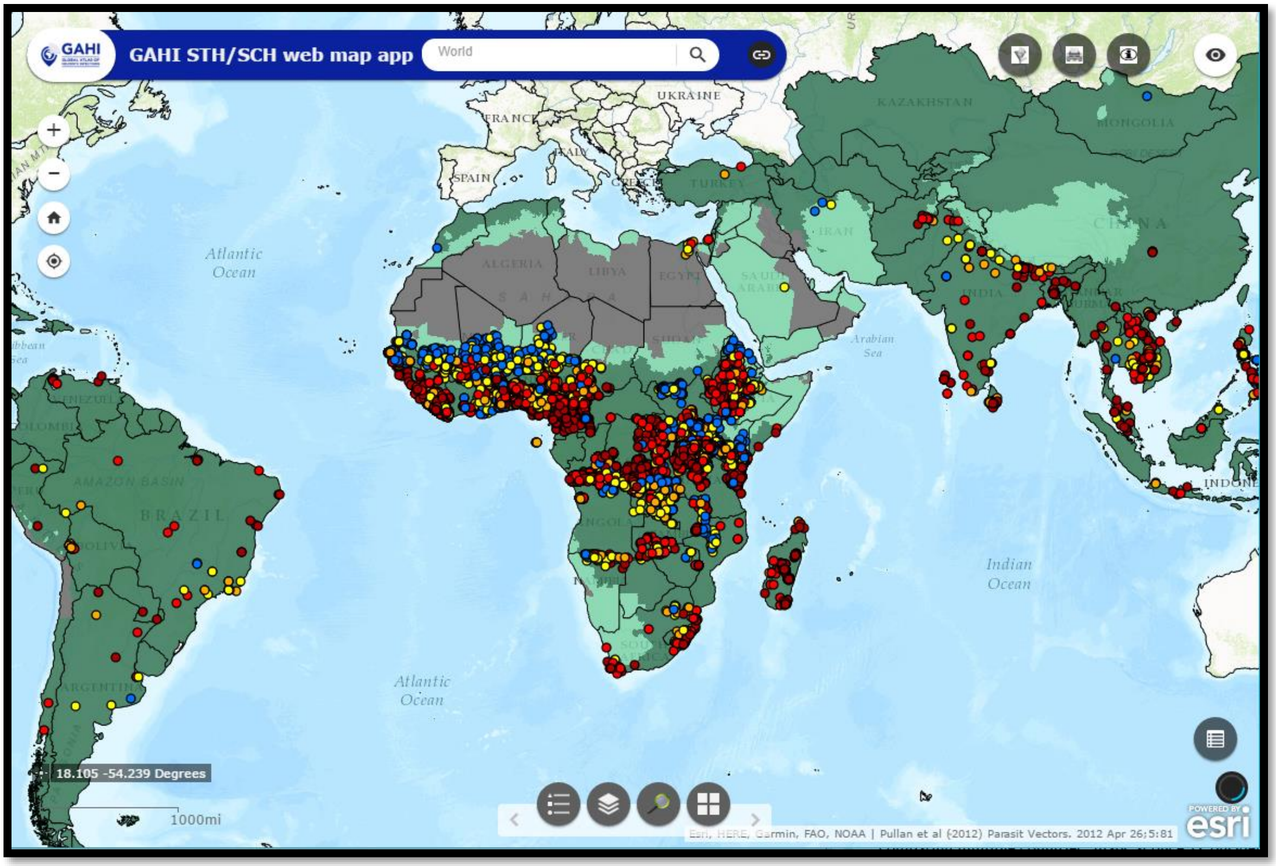


Figure 10 GAHI User Interface developed with Esri Web AppBuilder

2.1.3.3. Avia-GIS user survey

A significant outcome of analyzing the GAHI was the discovery of an extensive report developed by Avia-GIS on behalf of the GAHI about an end-user survey of 105 individuals from 45 countries, most of whom were affiliated with a NTD program (Avia-GIS 2012; Nikolay, Pullan, and Brooker 2013). Respondents were asked to rate the importance of twelve potential mapping tool functions for NTD mapping. The results of that survey revealed that users consider navigation (pan and zoom), display of raster and vector data, the ability to create a legend, and the ability to get feature information by clicking on the map to be mandatory map functions.

Important map functions include the ability to query the data, turn layers on and off, display the map full screen, and print or save the map. The report goes on to perform a comparative analysis of eleven NTD web mapping platforms and twelve non-NTD web mapping platforms, using the survey results to rate each application. The report also describes an in-depth methodology and performs an extensive software review of licensed and free open source software (FOSS) to aid in selecting the appropriate software for the job. Because of the application structure, end-user survey and thorough report, the GAHI was one of the most influential related works encountered in this thesis study. It should be noted that both the NTD MT and the GAHI shared the Avia-GIS report detailing desired GIS traits within an NTD mapping solution. As mentioned in section 2.1.1, the CFEP and eLibrary apps provide many of the desired web GIS workflows detailed in the Avia-GIS survey.

The GAHI invites user-contributed data via a simple web page, illustrated in Figure 11. This easy contribution process informed the user workflow for early stages of this research project. It asks a series of simple questions that must be answered as criteria for inclusion in the database. This simplicity of data donation is something to emulate. Figure 11 shows the GAHI Contribute Your Data webpage, which because of its plainness is not intimidating (as compared to multi-line, red-starred GNTD form shown in Figure 7). As mobile technology has improved and epidemiologists increasingly record GPS coordinates during epidemiological surveys, the GAHI now permits data at any scale to be entered into the database (GAHI 2016). The granularity of scale depends on how researchers record the location of their study area; at the regional or global level one single *x,y* coordinate would be a misrepresentation of the data, but at the local level, a single school (a common locator in epidemiological studies) is better represented by a point than a polygon.

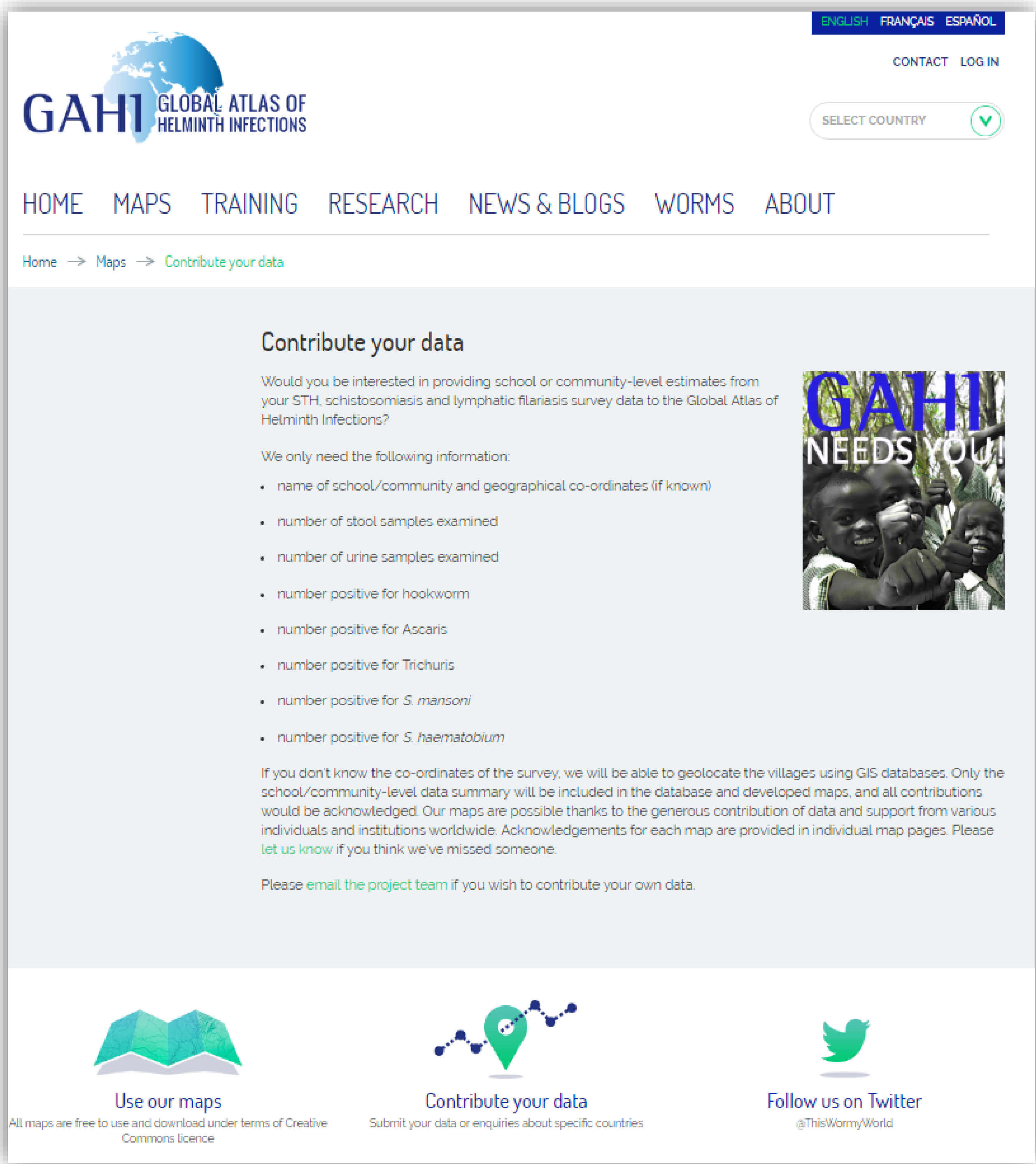


Figure 11 Global Atlas of Helminth Infections “Contribute Your Data” webpage

2.1.4. Global Atlas of Trachoma

The GAHI's success in attracting users inspired the construction of the Global Atlas of Trachoma (GAT) at http://www.trachomaatlas.org/ (Brooker, Hotez, and Bundy 2010). Published by the London School of Hygiene & Tropical Medicine, the International Trachoma Initiative (ITI), and The Carter Center, the GAT "aims to provide up-to-date and publicly accessible maps of the current distribution of trachoma for use by all partners in elimination efforts" and hopes that the maps prompt political action to aid implementation efforts (Trachoma Atlas 2016). The GAT is intended to consolidate from multiple sources published and unpublished data at the district level so that users can produce recent maps of trachoma distribution. The next section discusses the application's operational layers and key supporting technology, the LINKS open data kit.

2.1.4.1. GAT application description

While the app displays data globally, most GAT partners work at the local level and upload the data to the cloud, where it is cleaned, analyzed and ministry-of-health approved prior to inclusion in the GAT (Solomon et al. 2015). Sightsavers, the Global Trachoma Mapping Project (GTMP) grant manager and one of the major contributors to the GAT, used Android smartphone technology to develop a purpose-built LINKS application for the collection of individual-level demographic and clinical data in addition to household-level WASH data. The LINKS System, launched by the Neglected Tropical Diseases Support Center at the Emory Task Force for Global Health in June 2011, is a mobile data collection and cloud-based reporting system that in 2014 had already supported more than 100 different global health projects (Pavluck et al. 2014). Rebecca Mann Flueckiger, the primary researcher on the NTD MT and GIS Data Manager at ITI, was a contributing author of the Pavluck article and would later dynamically incorporate the LINKS/GAT data into the NTD MT. Other organizations using this data collection system include Washington University, The Carter Center, USAID, and the CDC, many using LINKS to collect trachoma data that ultimately appears in the GAT. For example, thanks largely to LINKS, the GTMP collected data for more districts in three years than had been collected in the previous twelve (Sightsavers 2016). Indeed, the GTMP was believed to be the largest global mapping campaign ever attempted (Mann 2013).

The GAT is a mapping application that supports cartographic overlay of resident data only and does not provide an option to view the source of or download source data. It is not designed to accept VGI from end-users, but rather has a strenuous review and approval process prior to public display on the GAT website. Layers include six years of prevalence data (2010-2015) and five years of treatment data (2010-2014) that reveal changes in endemicity over time as they are turned on and off. Additional summary layers of cumulative treatment over time, areas with a 50% reduction in trachoma incidence, and overall national endemicity are also available. Layers can be toggled on and off and using pan and zoom, users can print (or save to file) the resulting "custom" maps.

Interestingly, in addition to political boundaries at multiple administrative levels, there is a layer called Implementation Unit Boundaries, which do not necessarily match political boundaries. In order to ensure proportionate sampling with requirements that each evaluation unit represent roughly 250,000 people, some administrative boundaries were combined or split to make evaluation units meet that criteria (Mann 2013). This recognition that political boundaries may not be the best to use for treating diseases that do not respect human-drawn boundaries is unique among the applications reviewed in this chapter. Unfortunately, at the time of this writing, the User Guide link is broken and redirects the user to an error message, so no information about how to use the application is currently available online.

2.1.4.2. GAT application interface

Visually, there is a striking similarity between the GAT and the NTD MT interface version 2.0—both were implemented using the Leaflet open-source JavaScript library for mobile-friendly interactive maps. Figure 12 illustrates the web mapping interface for the GAT. Dynamic popups provide information about a geographic area, detailing the country, region, district, subdistrict (political, administrative units, and labels differ between countries), follicular trachoma category (level of endemicity), and survey year as the mouse moves around the map. Clicking on the map generates a stationary pop-up of the same information that must be closed

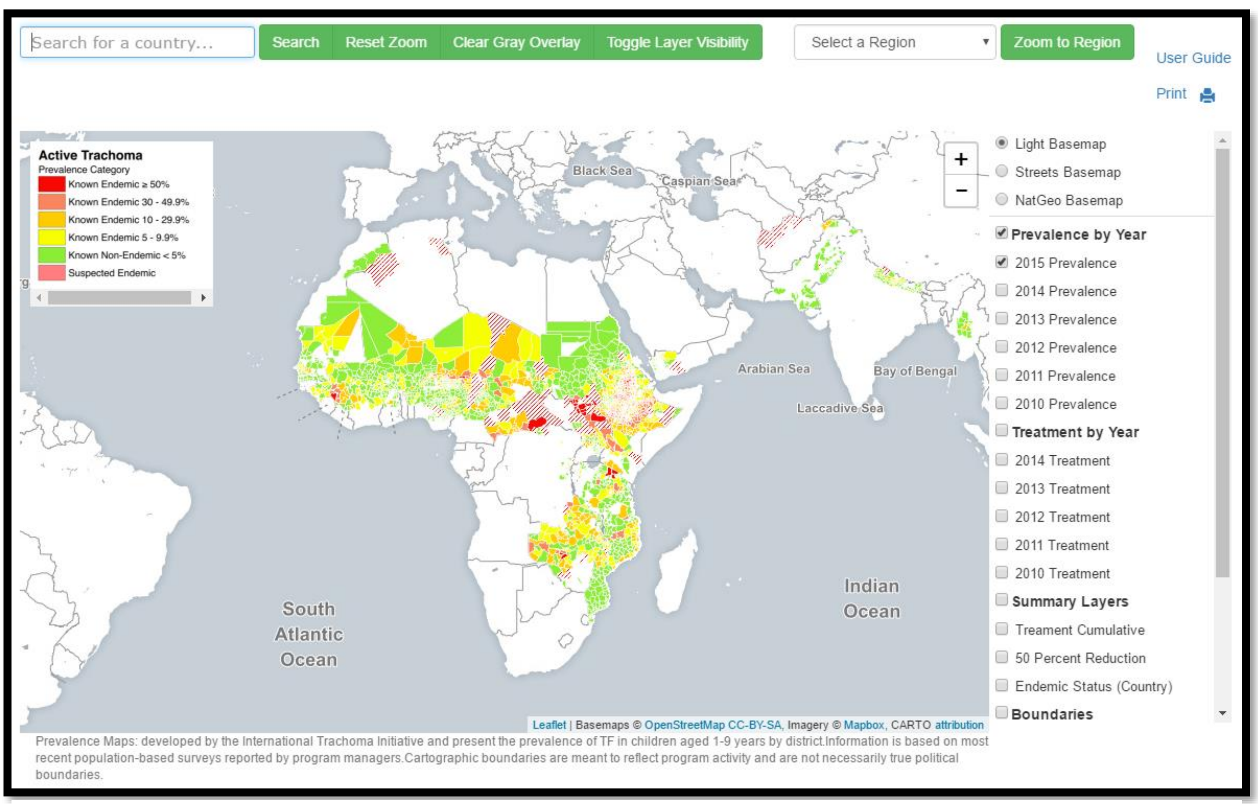


Figure 12 Global Atlas of Trachoma web map interface

using the X at the upper right-hand corner of the popup. When using the Search for a Country tool, the map zooms to the country the user types in and places a “clear gray overlay” on surrounding countries to emphasize the data for the queried nation. This helps users display only the data of interest, producing a more user-centric map. These maps can then be exported with and without the gray mask, and display any of the selected datasets at that scale with a dynamic legend.

This section reviewed similar studies in epidemiology, prevalence mapping, and online georeferenced epidemiological bibliographies. An examination of VGI follows, discussing the growing mobile phone ubiquity, participatory GIS, and popular epidemiology. Spatial data quality, credibility, and trust as they pertain to volunteered data are briefly discussed.

2.2. Volunteered Geographic Information

Michael Goodchild coined the term “volunteered geographic information” (VGI) in a 2007 paper, *Citizens as Sensors: The World of Volunteered Geographic Information*, which is now considered a seminal work on this topic. He defined VGI as “widespread engagement of large numbers of private citizens, often with little in the way of formal qualifications, in the creation of geographic information” (Goodchild 2007, 212). In other words, ordinary people could generate and consume their own spatial data, without the involvement of a government or commercial entity, thanks to new technologies. Section 2.2.1. delves into the topic of VGI, discussing its roots in Web 2.0 and the rise of neogeography. Section 2.2.2. describes participatory GIS (PGIS), or intentional VGI to achieve a common goal. Section 2.2.3. discusses the concerns many have about the accuracy, precision, and credibility of VGI as opposed to professionally-collected data. Section 2.2.4. touches on concerns of privacy in VGI, using social media and medical data as examples. Section 2.2.5 discusses the growing ubiquity of mobile devices and connected networks. Popular epidemiology, which is a blending of neogeography, PGIS, and epidemiology, is described in Section 2.2.6.

2.2.1. VGI, Web 2.0, and Neogeography

Goodchild cited Wikimapia, Flickr, and OpenStreetMap (OSM) as prime examples of VGI, but attributed much of the rise in ubiquity of the phenomenon to Google Earth and Google Maps. These programs put fundamental GIS capabilities in the hands of everyday people. Things that until then only had been possible to GIS professionals—pan, zoom, fly-by, turning search results on and off—became available to anyone with an internet connection and browser. Moreover, Google Earth and Google Maps provided individuals with the ability to “mash-up” data on those maps, creating theme-specific web maps that we now take for granted on the internet. Mash-ups use information from multiple sources to create a single, dynamic image or service to the user (Haklay, Singleton, and Parker 2008). The key word is *dynamic* and is founded on the concept of “Web 2.0,” describing the interactivity of services and applications on the internet (O’Reilly 2006). Tim O’Reilly posited that user engagement on the internet was shifting from a legacy of one-way procurement of information to a rich two-way communication (participation). Wikipedia is an excellent example of both Web 2.0 and mash-up; user-generated content and linking to other websites and services are key to both. Wikipedia empowers an immense community of users to modify and augment an online encyclopedia rather than having to rely on publishers to do so. Anyone can sign up for an editor account permitting them to change article content, request citation, and link supporting sources to an article. Another example of Web 2.0 is the “tagging” of photos, URLs and datasets with a user’s desired description or attribute, rather than having to choose between a pre-existing taxonomy (O'Reilly 2006; Haklay, Singleton, and Parker 2008).

Web 2.0 also reflected a growing change in the theoretical framework of the internet, and how websites are designed. The internet before 2004 was still largely accessed via dial-up modem, and generally involved one-way consumption of information. What O'Reilly and others called attention to was how the internet was quickly becoming a *platform* upon which interactive programs could be written, and the rapid-fire release of various APIs. The term platform in this sense refers to the underlying hardware or software of a system—much like Microsoft or Apple, or Android and iOS—and a defining concept of a platform is the existence of APIs and libraries for programmers to use. In this way, Web 2.0 was a precursor to software-as-a-service (SAAS), in which software is hosted on and served *from the web* rather than in a discrete software installation on one computer. Websites, and now apps on mobile devices, provide the user interfaces for these SAAS programs. Web 2.0 is so fundamental to how we use the internet in 2017 that in developed nations a distinction can no longer be made—one is simply on the internet in a participatory fashion all the time.

VGI obtained through direct user interaction can be tailored for a specific purpose. The roots of this are in "neogeography," described by Andrew Turner at O'Reilly Media in 2006.

> Neogeography means "new geography" and consists of a set of techniques and tools that fall outside the realm of traditional GIS. . . Essentially, Neogeography is about people using and creating their own maps, on their own terms and by combining elements of an existing toolset. Neogeography is about sharing location information with friends and visitors, helping shape context, and conveying understanding through knowledge of place.Lastly, neogeography is fun. (Turner 2006, 2-3)

At its core, neogeography is the performing of geographic data collection, manipulation, and presentation by non-professionals. Regular people now have access to the necessary tools to create and view spatial data through open APIs like Google Maps API, and now Esri's ArcGIS

API for JavaScript. Neogeography can consume VGI and present it in a mash-up as mentioned above, but it can also bring together data from hard-to-access sources and serve it to end-users for a specific purpose. An example of this is Zillow.com, a real-estate website that pulls data from auditors, school districts, police reports, the U.S. Census bureau, and homeowners, providing potential home buyers or renters with statistics, maps, and photos of potential properties. Neogeography can also be the act of tagging photos, creating maps of the make-believe world of *Game of Thrones*, or of using commercially-available handheld GPS to track a bicycle ride. It is the continuing development of OSM, the creation of Ancestry.com migration maps, and the origin of geocaching.

Despite the recreational examples provided above, neogeography can produce reliable data using "citizen science," or groups of people who act as observers for some field of science (Goodchild 2007). Examples of this include the Great Backyard Bird Count (GBBC) of the National Audubon Society and Cornell Lab of Ornithology. In the United Kingdom, the Royal Society for the Protection of Birds (RSPB) has a similar bird count called the Big Garden Birdwatch which last year captured records of over 8 million birds (RSPB 2016). These organizations engage birdwatchers worldwide to obtain an accurate bird count at a snapshot in time (Audubon, 2016). Participants are asked to observe and count birds in the United Kingdom during the annual four-day RSPB event and report those findings to the website www.birdcount.org. Key to the idea of citizen science is that participants are expected to have some level of familiarity or training, giving them (some) expertise in the field. Because users—in this case birdwatchers—are already engaged in the topic and are volunteering their expertise, this VGI is a good example of citizen science for a specific purpose (Goodchild 2007). Consider too that the geographic area covered by birdwatchers' participation in the GBBC and the Big Garden

Birdwatch is exponentially larger than professional ornithologists would be able to collect simultaneously. This purpose-driven VGI begins to illustrate the value of having non-professionals collect geographic data. At its core, VGI is generated by non-specialist users, often with the explicit intent to supply the information to specialists. These specialists can be continents away, but still access locally-gathered spatial data.

2.2.2. Participatory GIS

Participatory GIS (PGIS) intends to incorporate local knowledge into a GIS and “blend” it with expert information, while respecting the fact that most participating communities lack political, financial, and technical control of the project (Weiner and Harris, 2008; Dunn 2007). PGIS is designed with hyper-awareness that being involved in the creation of PGIS does not guarantee power to make decisions about the resulting product (Aitken and Michel 1994). PGIS is issue-driven, arising as a response to critiques that traditional GIS was too technical and disregarding of cultural considerations, even elitist. Community involvement and social awareness are emphasized.

Despite its aspirational beginnings, PGIS does have pitfalls that must be avoided. For example, CBOs may not necessarily represent the views of community members or have their best interests in mind. Second, cultural practices in developing countries may lead to significant portions of the population from being excluded in the design and use of the PGIS, as was the case in a 2002 study in Ghana where women were excluded from participation. Societal constraints or religious practices could prevent women or other marginalized groups from being able to engage in a PGIS project (Kwaku-Kyem 2002). To participate in PGIS requires internet accessibility. This concern is underlined by Consumer Barometer data from Google; in Nigeria in 2016, men were more than twice as likely to use a computer than women, and ten percent more men than women use a smartphone, at 72% and 62%, respectively (Google 2016). In Uganda in 2014, 77% percent of Ugandan men owned a mobile phone, while only 54% of Ugandan women did (PEW 2014). The very groups that PGIS is supposed to help may not be able to participate due to extreme poverty, remote location, or lack of electricity. Dunn also warns that transcribing vaguely demarcated boundaries into clearly defined lines may inadvertently cause conflict over land where conflict had not existed, and urges researchers to think about the political and social implications of the information once it is presented in a GIS (Dunn 2007; Rambaldi et al. 2006).

Dunn is quick to embrace the internet to scale up PGIS to achieve real-world, democratic change. She writes, “At one level, web-based GIS is the definitive form of participatory and democratic GIS since it has the potential, theoretically, to reach a limitless number of people and to elicit views rapidly and efficiently” (2007, 625). While recognizing the enormous advantages that VGI confers in PGIS, she and others raise concerns about data quality, accuracy, and privacy, discussed in the next sections.

2.2.3. VGI, Accuracy, and Credibility

One overarching concern among GIS professionals and academia about VGI is the absence of a guarantee of accuracy (Goodchild 2007; Foody et al. 2013; Flanagin and Metzger 2008; Rieh and Danielson 2007; Dunn 2007; Couclelis 2003). VGI is generated by non-professionals. Individual bias, deliberate tampering of data, and plain misunderstanding or ignorance can affect data quality and accuracy. This section explores the relationships between spatial data quality, accuracy, and semantics with regard to VGI.

“Accuracy” and “precision” are often used interchangeably in GIS, but have vastly different meanings. “Accuracy” is both a subjective rating of the quality of data—how closely the information on a map matches the real world—or a measurement of the likelihood of errors in a dataset. "Precision" refers to how exact the location or description of data is—in numeric terms it refers to the number of places behind a decimal point in *x, y* coordinates, thus indicating how close to the real-world the measurement can be. When referring to the exactness of data description, the issue of how data is defined must be addressed to ensure precision.

Key components of a deployed GIS include data standardization and a shared understanding of what data is being collected, and how it is defined. While some data has clearly defined attributes—height, distance from other objects, color, species—other data, especially geographic features, are harder to define. "Semantics," in terms of language and logic, refers to the many different meanings that words or phrases can represent. If something is "near," how that nearness is interpreted is different between people, because it is a subjective qualification of distance. When collecting (spatial) data, there must be an agreed-upon definition of feature classification to ensure the data output "means" what it is supposed to. One way to prevent data errors caused by differences in semantics is ensuring that everyone interprets the data in the same way, using "ontologies" (Hunter 2002).

Ontology is the collective understanding of a definition of *something*; for example, we have a collective understanding of what a mountain is when we see it. However, while we may know it when we see it, answering the question "what is a mountain?" can be very difficult. Smith and Mark (2003) use a mountain—a discrete object when viewed from afar but hard to categorize between "mountain" and "not-mountain" while walking up one—to illustrate the difficulty in defining geographic entities, many of which change gradually across a continuous field. (A detailed discussion of object v. field in geography can be found in Couclelis 1993.) Ontology is meant to formalize or quantify an object or feature's definition within a framework by creating a logical semantic structure for inclusion in an information system (Smith and Mark 2003). Data classification is thus essential for PGIS to ensure that data is being interpreted in the same way by all volunteers, ensuring categorical data precision.

Ontologies can differ between societies and are often affected by differences in geography. This difference is made stark in Mark & Turk's 2003 article detailing the different landscape categories among one aboriginal culture in western Australia. They argue that ontology is a "stipulated taxonomy that forms the basis of a data dictionary used in building an information system" (Mark & Turk 2003, 29). Mark and Turk compare the Yindjibarndi and English terms for water bodies (i.e. lakes) as proof for a need for an established ontology and defined relationship between categories prior to building a GIS. This article also serves to underscore the importance of understanding the peculiarities of a particular region or culture before constructing a PGIS. Since western Australia is arid, the aboriginal definition of a "lake" would be very different from a Floridian definition, where water is abundant.

The issues of semantics and meaning raise concerns about the fitness of VGI in terms of quality and accuracy. Bishir and Kuhn (2007) argue that semantics, along with incomplete metadata and little or no professional oversight, can negatively impact the usability of data generated by volunteers. As an alternative, they suggest "Social Tagging," or keyword and tag creation as a substitute for metadata—not to replace a proper taxonomy but rather to facilitate the production of valuable metadata that doesn't require spatial expertise to manufacture. Vander Wal plays with the language of the idea of a self-created taxonomy, using "Folksonomy" to define a user-generated classification system through tags (Vander Wal 2007). Automated tagging is another option for classifying data (such as EXIF data embedded into photographs), but the Bishir and Kuhn still suggest *Who*, *What*, *Where*, and *When* as generic tags to be supplied by the volunteer. Further, they argue that trust should be used as a proxy for VGI quality, giving users the option to rate or "socially endorse" the data itself for trustworthiness as an alternative measure of information quality (Bishir and Kuhn 2007). Another suggestion for quality assurance is to open data up for correction to a community of users, like Wikipedia, Wikimapia, and OpenStreetMap (Goodchild 2008). Continuing this discussion of trust and VGI and discussing subjective credibility, Flanagin and Metzger, in reviewing a 2000 article by Frank Fischer, had this to say:

> Conceiving of credibility as a perceptual variable highlights the fact that trust and expertise are problematic terms. For example, information science perspectives that view credible information as only that which is "accurate" lean too heavily on expertise: nonexperts can also be credible, and many studies have found instances where local knowledge or expertise has eclipsed that of credentialed experts. Experts are also wrong sometimes, even though they may be trusted. So, who is an expert and whether those experts draw the trust of others can be separated from the accuracy of the information they provide. (Flanagin and Metzger 2008, 141)

This discussion of these "problematic" terms clearly draws a line between desirability and practicality—while an accurate, precise dataset is desired, the data being collected isn't always objective, and professionals can't always be the ones collecting the data. Flanagin and Metzger go on to discuss two types of credibility—the United States Geological Survey is used as an example of "credibility-by-accuracy" where authority and expertise plays a huge role in perceived credibility when data is scarce. Most VGI, they argue, are examples of "credibility-as-perception" where contextual believability is more influential than scientific accuracy; that is, most PGIS are socially or politically based, not scientific studies.

VGI is increasingly used by professionals who, for reasons of cost, proximity, or Big Data volume cannot collect the data themselves. Giving the public power by requesting help to *create* data is in effect qualifying or classifying their volunteered knowledge as being of equal to or greater value than that of professionals or academics. From a technological perspective, Rieh and Danielson argue that the credibility of VGI is an increasing concern due to the combination of the quantity and accessibility of digitally stored and transmitted information, which creates greater uncertainty about who is responsible for the information. This uncertainty in the digital media environment makes traditional data governance difficult due to the volume of data being generated; vetting by a single individual is impossible (Flanagin and Metzger 2008; Rieh and Danielson 2007). Despite the challenges of data accuracy, validity, and credibility, in resource-poor settings it may be that the only spatial data available is VGI. In the absence of professionally-collected spatial data, it could be argued that the data should be considered authoritative because the public is invested in a local project's outcome, and no alternatives exist.

Section 2.2.3. discussed the concepts of data accuracy and precision, semantics and ontology, and argued that VGI can be considered authoritative in the absence of professionally-collected data. Section 2.2.4. briefly touches on VGI and social media to discuss privacy in VGI, and then discusses the responsibility of maintaining patient privacy in an epidemiological PGIS.

2.2.4. VGI, Social Media, Medicine, and Privacy

In the United States, Google Maps is perhaps the most well-known example of VGI. Users can get directions, upload photos tagged with locations, write reviews of businesses, create and upload features using KML (an open-source spatial file format written in keyhole markup language), and see traffic along driving routes. Intentional upload is deliberate VGI; rating a barber is wholly voluntary, and geotagged photos don't post themselves. However, not all users may understand how completely Google may be able tracks a person's physical location. On the Google Maps application install, users can choose to agree to an end user license agreement (EULA) giving Google permission to mine "anonymous" location data, including search terms, GPS coordinates, and velocity to improve the overall Google Maps user experience. This is an increasingly common caveat in many EULAs that few users ever read to, or at least not consider its significance. This data enables Google Maps to offer users in many American cities up-to-the-minute traffic jam data superimposed on its maps, gleaned from user data—even when users are not touching their phones. Because Google Maps' user base is so large, this creates an enormous amount of data to be mined. From 2014 to 2015, Google Maps ranked sixth in the top 25 mobile apps (comScore 2015). And, since Google Maps is in many cases tied to a Google (Chrome browser) login, even when users are using an internet browser on a work computer or laptop at home, Google knows where they are. For the privilege of using the Chrome internet browser, Google knows where people live, what they search for, and what websites they visit. This (albeit-voluntary) breach of privacy is one of the concerns raised by Goodchild in his 2007 deep-dive into VGI.

Facebook, Twitter, and Snapchat "check-ins" are also examples of VGI, as are most posts on Instagram (ranked first, fourteenth, seventeenth and ninth, respectively, per the 2015 comScore survey). Whether user-initiated or automatic, check-ins place the user in a specific place at a specific time, sometimes even when an app is not in use. Online powerhouses like Google and Facebook buy (and peddle) this data to better sell location-based advertising, or advertising that changes based on a user's physical location or patterns of movement. This VGI is increasingly valuable in terms of online advertising, but from the individual perspective the sharing is unintentional and automatic, but, in the case of these apps, *required* in order to share the full user experience. If a user *is* concerned about their privacy, it is possible to prevent the apps from accessing "Location Services" in the device settings, but this may preclude use of the app when it is opened next. The amount of VGI generated by social media (with mobile devices acting as sensors) is so large that it has spawned its own sub-field in Geography and in Data

Science—Big Data—a blending of computer science and geography that now exists to address the growing amount of data and developing technology that can analyze it. (It should be noted that the term Big Data is used for any very-large dataset that requires extensive computing power to analyze, but in the context of the study of geography, it refers to very-large geographic datasets, and more and more refers to crowdsourced social media content.)

While a lively academic debate about privacy and VGI is ongoing, an August 2015 survey of smartphone users revealed privacy may not be much of a pressing concern as originally thought (comScore 2015). 42% of respondents agreed with the statement "I am comfortable with apps accessing my geographic location information" as opposed to 31% opposed (28% neither agreed or disagreed). The same survey revealed that people are more annoyed by the intrusiveness of push notifications than they are concerned with sharing their geographic information, one reason being that an unwillingness to share that data (refusing the EULA) means they are excluded from using the desired app. More and more, users will be "missing out" on a common social experience if they do not agree to the level of data-sharing required by an application upon install.

Unlike social media and the exchange of privacy for a perceived benefit, medical data must be kept private by ethical and legal requirement. Within the United States, the Health Insurance Portability and Accountability Act of 1996 (HIPAA) provided for data and security provisions to safeguard patient medical information. The Act was a huge body of work addressing a number of concerns in the healthcare industry, but it is now most known for the guarantee of data privacy that each person visiting a doctor's office is provided with. Patient privacy laws in countries outside the United States vary; when discussing patient demographic data from multiple continents it remains to be seen which country's laws should be adhered to.

When considering that spatial data also records a person's location, it falls upon the GIS designer to determine how best to de-identify the data or take measures to secure the database. Even if names and identifying characteristics are not collected, is it ethically sound to put an *x,y* coordinate on a map indicating that someone with a particular disease or condition lives there? This author thinks not; even if the patient in question and his peers do not have access to the PGIS, can the patient really comprehend this "loss" of privacy? If no, then the researcher should not be putting that privacy at risk. In the case of tungiasis, ostracism is immediate once the condition is discovered; how then can researchers willingly give away someone's privacy? One option is to set visible extents for the data and remove access to the coordinates themselves; this allows for visible comparison down to a certain zoom level at which point the data can't be viewed on the map any more. Another option is the aggregation of points to polygons, but this introduces the modifiable areal unit problem, where this aggregation can introduce significant statistical bias depending on the size of the unit chosen to be visualized (Openshaw 1983). Lastly, access to the GIS can be restricted, which then brings up the conflict of data ownership raised in Section 2.2.2. when discussing the desire of PGIS to include members of the community in the GIS' design and deployment. If the data must be restricted to just a few, locals' trust in what it is being used for will begin to erode.

Section 2.2.4. touched on the exchange of privacy for convenience that Google Maps (and other apps') users voluntarily give away, and discussed how apps are selling location-based data to target advertising. It very briefly introduced the concept of Big Data but made a distinction between the VGI produced by social media and the type of VGI that involves direct user interaction and intentional volunteering of data. This section brought up concerns with the privacy of patient medical information and suggested a few methods of reducing the identifying details that comes with spatial data, but does not excuse the GIS developer from protecting the data of patients.

Even accepting the requirement of civil society to provide and protect massive back-end infrastructure, we cannot interact with the internet or each other without the intermediary mobile device, such as a smartphone. The following section discusses the growing ubiquity of mobile devices and data networks in developing countries with the intent of showing that the use of mobile devices to collect epidemiological data in developing countries is not only a possibility but fast becoming reality.

2.2.5. Mobile Device Ubiquity

The pervasiveness of the smartphone in developed countries enables users instant access to the internet, social media, and web mapping, and these activities are undertaken without thought daily by millions of people. A computer requires peripheral devices (mouse, monitor, modem), reliable electricity and a data connection to access the internet—large hurdles to overcome for poorer populations in developing nations—so it is no surprise that computer penetration statistics from Google's 2016 Consumer Barometer show very low numbers of household computers in Africa (Google 2016). Conversely, a mobile device uses a fraction of the electricity that a computer does, stores the surplus while not in use by battery (that can be charged with solar power or other fuel-based generator), and can be accessed from any place its owner remembers to bring it. Its connectedness is built in via its cellular and wi-fi adapters, and it has hardwired local memory to store images, messages, data, and applications. In developed nations, these applications, or "apps," are an increasingly popular way to interact not only with each other but with the world around us. Especially in the case of social media, VGI is collected rather than willingly volunteered—upon app install we must accept an end-user agreement giving permission to the app to mine usage (and often location) data. This exchange of privacy for functionality is one that occurs almost without thought for most smartphone users. Every time we tag a local Starbucks, respond to an online survey, or even have Google Maps open and running, our geographic data is being “volunteered” for us, and consumed by media giants for financial gain. Several articles and books now deal with the concept and ethics of “Big Data” in general (Kitchin 2013; Wu et al. 2013; Richards and King 2014), crowdsourced data (Crampton et al. 2013; eds. Sui, Elwood and Goodchild 2013) and the ethics of crowdsourcing data in particular (Taylor 2015; Harvey in eds. Sui, Elwood, and Goodchild 2013; Lazer et al. 2014; Rambaldi et al. 2006; McGranaghan 1999). However, for the purposes of this thesis, VGI is intended to represent intentional, active volunteering of data via applied web GIS. The only volunteers are those that have a stake in the research and management of this disease, and their participation is not automatic but active.

Smartphone ubiquity is beginning to extend into developing countries, promoting social justice by giving an equal digital platform for individuals trapped in poverty. For example, according to Google’s 2016 Consumer Barometer, smartphone uptake was at 44% in 2016 compared to 27% in 2014 (Google 2016). Broken down further, over 57% of individuals under 25 and 55% of individuals 25-34 used a smartphone in Kenya in 2016, a very sharp divide from the 10% of those over 55 years of age (Google 2016). Smartphones facilitate safer financial transactions, especially for women (Suri and Jack 2016). As physical currency is removed from a financial transaction, robbery and violence are less likely to occur. In fact, smartphones now provide financial services relevant to a growing number of individuals at the margins of, or outside, the formal financial system (Villasenor, West, and Lewis 2016). The Communications Authority of Kenya reported 26.3 million mobile money subscribers between April and June of

2016 (Communications Authority 2016), and as of 2016 almost 50% of Kenyans population is now online (Google 2016). One study in *Science* indicated that as many as 194,000 households were lifted out of poverty due to access to mobile money and that access has improved the economic lives of poor women and members of female-headed households (Suri and Jack 2016). In addition to expediting financial transactions, smartphones enable farmers in SSA to communicate with each other about nearby sightings of large herbivores and their predators. As part of National Geographic's Big Cats Initiative, villagers now receive text messages informing them of lion prides hunting near livestock that are generated when radio-collared lions cross predetermined "geofences." Once the location of the lion has been mapped, the data is disseminated via text message phone tree to notify participating villagers (Dollar 2016). Another project aims to use the same concept of GPS collars and geofences to continuously track the movement of almost 100 elephants to be able to alert residents of their proximity (Wall et al. 2014). These examples would not be possible were it not for the ubiquity of mobile phones and, increasingly, smartphones, and their supporting cellular and data networks.

Humanitarian aid workers often carry mobile devices with offline capabilities when working in the field; these web GIS are simply extending the uses of those devices to facilitate epidemiologic mapping and disease management. In contrast to live smartphone data-collection, the Tungiasis eLibrary uses a browser-based web GIS to collect VGI through a mapping application interface. The app *has* a mobile interface, but for the type of data being collected—literature citations—it is far *easier* to use the application on a computer with a regular keyboard. Users can volunteer links to scientific literature, or upload specific disease prevalence after analysis has been performed. Thus, in the context of the combined CFEP and eLibrary project, VGI is further subdivided into two types based on intended users. Field workers are targeted for the CFEP, while academics, researchers, and policy-makers are targeted by the Tungiasis eLibrary. Having discussed the growing availability of connected and disconnected mobile devices in developing countries, it is time to look at one specific way of using those devices. Section 2.2.6. discusses Popular Epidemiology, a combination of VGI, PGIS, health education, and epidemiology.

2.2.6. Popular Epidemiology

Popular epidemiology is epidemiological mapping utilizing VGI. It capitalizes on local knowledge—geographic, social, and political—in a number of ways to provide healthcare professionals with prevalence data for research purposes. Popular epidemiology also promotes the dissemination of high-level information at a local scale. Fischer (2000) posits that popular epidemiology draws attention to otherwise ignored local health disorders and enables communities to press for change by raising consciousness of local health concerns. He argues that popular epidemiology is in and of itself a methodical strategy that can lead to actual political change (Fischer 2000). Despite this positive sentiment, however, popular epidemiology is not without risk. Fischer flips the coin, discussing the difficulty of organizing and nurturing ongoing citizen participation, and laments the loss of quality of participation over time. In fact, he posits that it would be better to give up entirely than fail, for failure will be used to argue against future PGIS/Popular Epidemiology endeavors.

This raises interesting questions for this research project, namely its feasibility and its potential for future use. If a PGIS is created to help combat tungiasis and it—for any number of reasons—were to fail, would an endeavor such as this be likely to be repeated? Or, would only the negatives be discussed, with little to no recognition of positives that could be applied in future work? On the surface it appears that the blending of PGIS, VGI and epidemiology is perfect for an application like the CFEP, which tracks vector-based diseases in resource-poor settings. Since there are no authoritative spatial distributions of tungiasis at local, regional, or global levels, it seems (from an outside perspective) legitimate to use locals to collect the data. Popular epidemiology appears to solve problems of skyrocketing costs of data collection, secluded communities that are suspicious of or uncooperative with "outsiders," and incompleteness of datasets. It is in this vein that this thesis suggests the use of PGIS and popular epidemiology to map the prevalence of *T. penetrans* and tungiasis in endemic communities.

This chapter attempted to review related applications that provide GIS or apply GIS to the control of neglected tropical diseases, comparing parts of each of four web GIS applications to use within the CFEP and Tungiasis eLibrary apps in this thesis project. The concept of VGI was introduced, along with subtopics of PGIS and popular epidemiology. The next chapter discusses the technology behind the CFEP and eLibrary apps, including software selection, back-end architecture, entity-relationship diagrams, and the overall selection of web GIS for this project's purpose.

Chapter 3 Technology

The CFEP and Tungiasis eLibrary web mapping applications share similar file structures and database construction processes. Section 3.1 discusses the software selection for the project and briefly introduces the Esri Development Center (EDC) designation. Section 3.2 describes the back end architecture and database design supporting both the CFEP and the Tungiasis eLibrary and provides multiple entity-relationship diagrams (ERDs) graphically representing the database structure. Section 3.3 explains the required client technology and addresses the use of web GIS instead of Mobile GIS for this project's purpose.

3.1. Software Selection

In order to design and implement a web mapping application that accepts VGI, network storage must be used to house the underlying database and its contents. Server space, whether physical or cloud-based, requires equipment, electricity, network connectivity, human power in the form of database and network administrators, software (operational and security), and money. To implement and register a geodatabase, a GIS software is required. Unless the software is open-source, a site license is required; a license for Esri ArcGIS 10.4 has been provided by the University of Southern California for this thesis project. Access to an institutional AGOL account is necessary to utilize essential functions of WAB, provided for this project by USC SSI. WAB is a graphically-based software development kit that enables non-developers to quickly create HTML and JavaScript-based GIS apps that run on any device. WAB was used to design the interface and functionality of the web mapping applications. Experience using the GIS software was required, as were skills in cartography, web design, communication, and web programming. A familiarity with scientific literature and the disease or parasite—in this case, *Tunga penetrans*—was essential, as is a deep understanding of the fundaments of GIS and databases.

This project utilized Esri's ArcGIS suite of software (ArcMap 10.3 and ArcGIS for Server 10.2) to prepare data, implement and register a file geodatabase, create coded domains to maintain data integrity, define relationship classes between datasets, perform cartography, and publish Web Map Services (WMS) and Web Feature Services (WFS) to AGOL, Esri's software-as-a-service online (SAAS) GIS portal. WMS and WFS are Open Geospatial Consortium (OGC) interface standards that deliver maps and data, respectively, in response to a user request (Jones and Purves 2008).

ArcGIS was chosen over other GIS and mapping APIs due to both the author's familiarity with the product and because of the program's ubiquity within GI Science. While excellent customizability is exhibited in Leaflet and GitHub's customizable map viewer (CMV)—an open source mapping framework built with the Esri JavaScript API and the Dojo Toolkit that sports a significant developer community presence—it is the ease-of-use and seamless integration between Esri's desktop and online platforms that made ArcGIS the better choice for this project. A major advantage to using ArcGIS products is Esri's adoption of REST service endpoints. REST endpoints are browser-cached uniform resource identifiers (URIs)—or links—to a specific network location where relevant data resides. REST services use the hypertext transport protocol (HTTP) web protocol to direct interactive applications to a network location when an application requests the relevant data. When the data changes, either by the database owner or other users, all applications that consume that data via a REST service endpoint are also updated seamlessly behind the scenes. The REST service endpoints that are automatically generated when a WMS is published also provides a URI for non-Esri users to consume the data in a non-Esri GIS. This means that data can be dynamically refreshed by the data provider without manual data and GIS layer updates being required on a public-facing web map, as is the case with static web map-based websites

Another benefit to using ArcGIS is its significant product documentation and various independent developer communities that have evolved along with the company. Esri's product support, virtual campus training, webinars, knowledge base, and user community collectively provide new and advance users with multiple avenues for assistance and learning. USC's designation as an EDC provides SSI students with communication pipelines direct to Esri software developers. Lastly, Esri products published through ArcMap and AGOL are visually appealing to use.

3.2. Back End Architecture and Database Design

Because all database construction for this project was performed using ArcGIS Server, both applications' database structures rely heavily on Esri's Geodatabase subtypes and domains rather than discrete SQL tables created in a traditional relational database management system (RDBMS). The enterprise-level geodatabase used integrates seamlessly with SQL Server to store tables of information that may or may not relate to other tables within the database, and may or may not be spatial data. The geodatabase also stores relationships between tables and can accommodate attachments like images or documents. Tables representing coded domains to support data normalization are made simple by Esri's subtypes and domains, accessed in the Database Connection Properties in ArcMap. Graphically, the subtypes are represented as related tables in ERDs in this chapter.

3.2.1. Entity Relationship Diagrams

The eLibrary uses one single point feature class to visualize the locations of tungiasis studies and research. The CFEP's database design is somewhat more complicated than the Tungiasis eLibrary. The CFEP contains several layers of supporting data in addition to its three VGI datasets *Home_Visit*, *Individual_Demographics*, and *Service_Area*. These extra layers support the research objective to demonstrate the unique fitness of web GIS for disease and vector management. Each layer can be turned on and off, or be used in common GIS workflows such as overlay, spatial aggregation, and buffer creation (when logged into an AGOL organizational account) with the intent to demonstrate how spatial analysis can be used to identify potential tungiasis hotspot areas. The tables are housed in a publicly-available web GIS and represent various environmental and social risk factors for the disease. Tables range from census-derived poverty data to rainfall isopleths, prevalence of livestock by type, location of primary schools (containing attributes from which several operational or interactive layers are derived), water access points, locations of medical facilities, and malaria endemicity. Since their only relationship with each other is spatial, these "data discovery" datasets are discussed in Section 4.1.1. The VGI-derived operational layers and their coded domains are represented graphically here with entity-relationship diagrams.

The entity-relationship diagram for the *Home_Visit* table in Figure 13 shows that it contains fourteen fields. The ObjectID and Shape fields describe the unique ID, or primary key, of the feature, and describe its location on the earth in an Esri format. The object of the table is to record data about sleeping shelters where *T. penetrans* has been found. Attributes are collected about the shelter to help researchers determine shared risk factors that could be addressed preventatively. Floor type is an indicator of tungiasis risk. The Floor_Type field is restricted to a list of coded domains including bare earth or soil, cement or concrete, wood, or other. The Interior_Sprayed field is restricted to a Yes/No domain, while the Exterior_Sprayed field has four options: No, Walls Only, Up to 1m from walls, 1-5m from walls, and "From structure to structure." The Spray_Persistence field records the duration of time that a pesticide remains active, and allows data entry in the form of a range of 1-6 months. Whether or not livestock are kept inside overnight (a common practice in areas relying on subsistence agriculture for survival) is recorded using a Yes/No domain in the Livestock_Indoors field. The presence of pets within the sleeping area is another risk factor, since *T. penetrans* readily parasitizes cats, dogs, and other warm-blooded animals. The Pets_Indoors field is populated with one of the following values: No, Dog, Car, Cog & Cat, and Other. Because rats and mice are such important disease vectors, the present of rats in and around the sleeping shelter is recorded in the Presence_of_Rats field with available values of Rats, Mice (but not rats) and No. The provision of shoes during the home visit is recorded in the Shoes_Provided field, with optional answers of No, Children, Adults, and All Family Members. If volunteers leave a topical treatment at the shelter, it is recorded as one of five values in the Topical_Given field: No, Petroleum Jelly, Potassium Permanganate, Ivermectin, and Other. The distance each household must walk to reach safe drinking water is recorded in the Distance_to_Water field as a measure of how easy or difficult it is to use water to wet floors (an effective method of smothering the fleas and eggs). Values in the coded domain include Indoor Potable Plumbing, Well (<50m), Well (50m to 500m), Well (500m to 1km), Well (1km to 2km), Well (>2km), Open Water (<1km), Open Water (>1km), and Other. Methods of waste disposal are recorded by one of six values in the Wastes_Disposal field: Indiscriminate, Leak Tin, Open Latrine, Closed Latrine, Toilet, and Other. Lastly, an Attachment field indicates the presence of an uploaded file in the *Home_Visit_ATTACH* table within the geodatabase. In the case of the CFEP, this would include photos, documents, or other relevant files. The *Home_Visit_ATTACH* table contains fields describing the content type, the attachment name, the data size, and the data itself, which is stored in the binary large object (BLOB) data type. Figure 13 shows the ERD for the *Home_Visit* table.

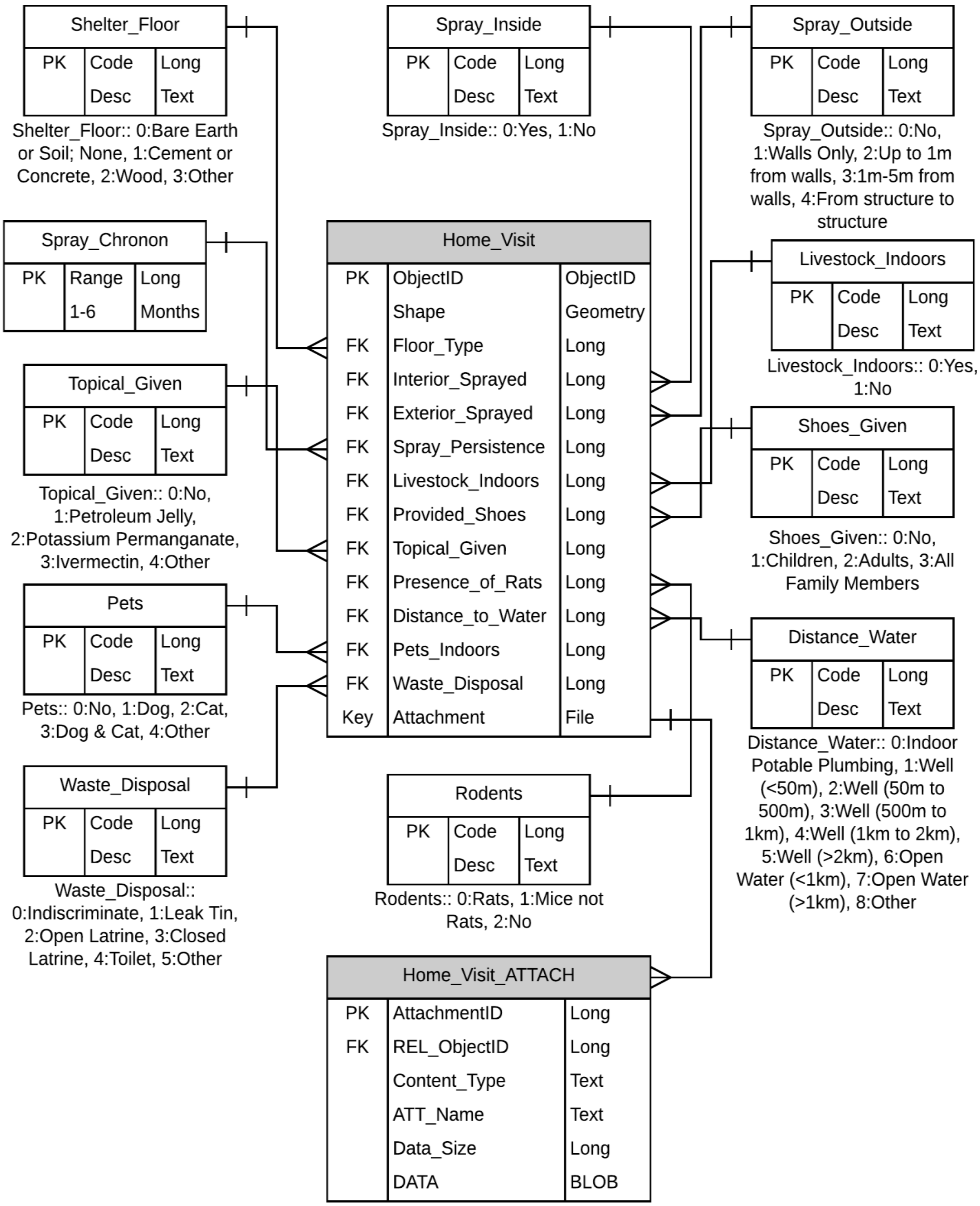


Figure 13 Entity-relationship diagram representing the *Home_Visit* table of the CFEP

The *Individual_Demographics* table is the most complex within the VGI series. The table records health and demographic data about afflicted individuals. Aid workers visiting an area for intervention or education would enter data. Attributes would be collected about patients to help researchers determine shared risk factors that could be addressed preventatively, or used for predictive modeling. The entity-relationship diagram for the *Individual_Demnographics* table shows that it contains 31 fields. The ObjectID, Shape, and ATTACH fields are the same as the *Home_Visit* table. The Gender field records whether an individual is male or female, while the Age field provides a domain of descriptors and ranges. Age is recorded as Infant, Toddler, 3-5 years, 6 to 8 years, 9 to 11 years, 12 to 15 years, 16 to 19 years, 20 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years, 60 to 69 years, 70 to 79 years, 80 to 89 years, and 90+ years. The Infant and Toddler descriptors were used so that aid workers could readily classify a young child without having to ask for a birth date. The use of age ranges was intended to aid in the protection of patient privacy by not using exact age; by reducing specificity a critical identifying detail is reduced to a class, not a number. The In_School field accepts answers of Yes, No, and NA (for adults who are not of school age). The School_Toilet field records a Yes/No answer if the individual's school has a toilet. The Duration field records the length of time the individual has been afflicted with tungiasis, with options of Less than 4 weeks, 1 to 3 months, 3 to 6 months, 6 to 12 months, 1 to 2 years, 2 to 5 years, and 5+ years. The Repeat_Infestation field records whether or not the individual has had tungiasis in the past. A patient's mobility is documented in the Able_To_Walk field, which accepts Yes/No answers. Whether or not patients own shoes or are being provided with shoes is recorded in the Own_Shoes and Given_Shoes fields, respectively. The Special_Needs field records if the patient has a physical disability, an intellectual disability, both, neither, or if there are age-related special needs. The

Shelter_Floor_Type field uses the same domain as the field of the same name in the *Home_Visit* table. The author acknowledges that this records the same data twice, which is contrary to the fundaments of database normalization. However, there are several scenarios in which an individual might be interviewed for the *Individual_Demographics* table but would not have their home visited for pesticide application. The School_Floor_Type uses the same domain to record the school floor type. Many aid organizations visit schools to maximize the number of people to whom they can provide relief. Schools are locations known well enough by all community members and generally close enough to walk to such that community engagement can reach a large percentage of the population. The Bedding_Type field records data about sleeping conditions in the home shelter to help identify homes where donated bedding might significantly reduce reinfestation. Acceptable answers in the domain include None/Bare Soil, Rags or Cardboard, Bare Mattress on Floor, Wooden Bed without Mattress, Wooden Bed with Mattress, Hammock, and Other. Whether or not the patient wets the bed is recorded in the Bedwetting field, and whether or not bedding is shared with others is recorded in the Share_Bedding field. The Is_Caretaker field records if the patient provides care to others, providing options of Yes/My Children, Yes/My Grandchildren, Yes/My Parents/Grandparents, Yes/Other, and No. Marital_Satus field records if a patient is Married, Single, Divorced, Widowed, In a Relationship, or NA (a child). The Needs_Caretaker field records if the patient is themselves cared for by others. Education attainment is recorded in the Education field, accepting answers of Beyond School Age, In School, Supposed to be in school but left because of tungiasis. The Employed field records similar answers of I'm a Child/In School, Yes, No, and No Due to Tungiasis. The Health_Conditions field records what, if any, other diseases or conditions patients have, with answers of None, Sickle Cell Anemia/SCD, HIV/AIDS, Malaria, Tuberculosis, Elephantiasis, Dengue Fever, EBVD Survivor, Leishmaniasis, Trachoma, and Other. The Future Work section of this thesis discusses the need to be able to select multiple answers in this field since multiple disease comorbidity is so common with NTDs in general. Like in the *Home_Visit* table, the Distance_To_Water field records how far the patient must travel for access to potable water, and its source. Additionally, the Waste_Disposal and Livestock_Indoors fields record the same data as the same fields in the *Home_Visit* table. However, the type of livestock is also recorded in the *Individual_Demographics* table, accepting the following entries: Chickens, Ducks, Goats, Pigs, Cattle, and NA. Whether or not an individual has pets is recorded in the Pets field, and the presence of rats is again recorded. Lastly, a comments field permits the input of text up to 50 characters to record additional pertinent information. Figure 14 shows the ERD for the *Individual_Demographics* table.

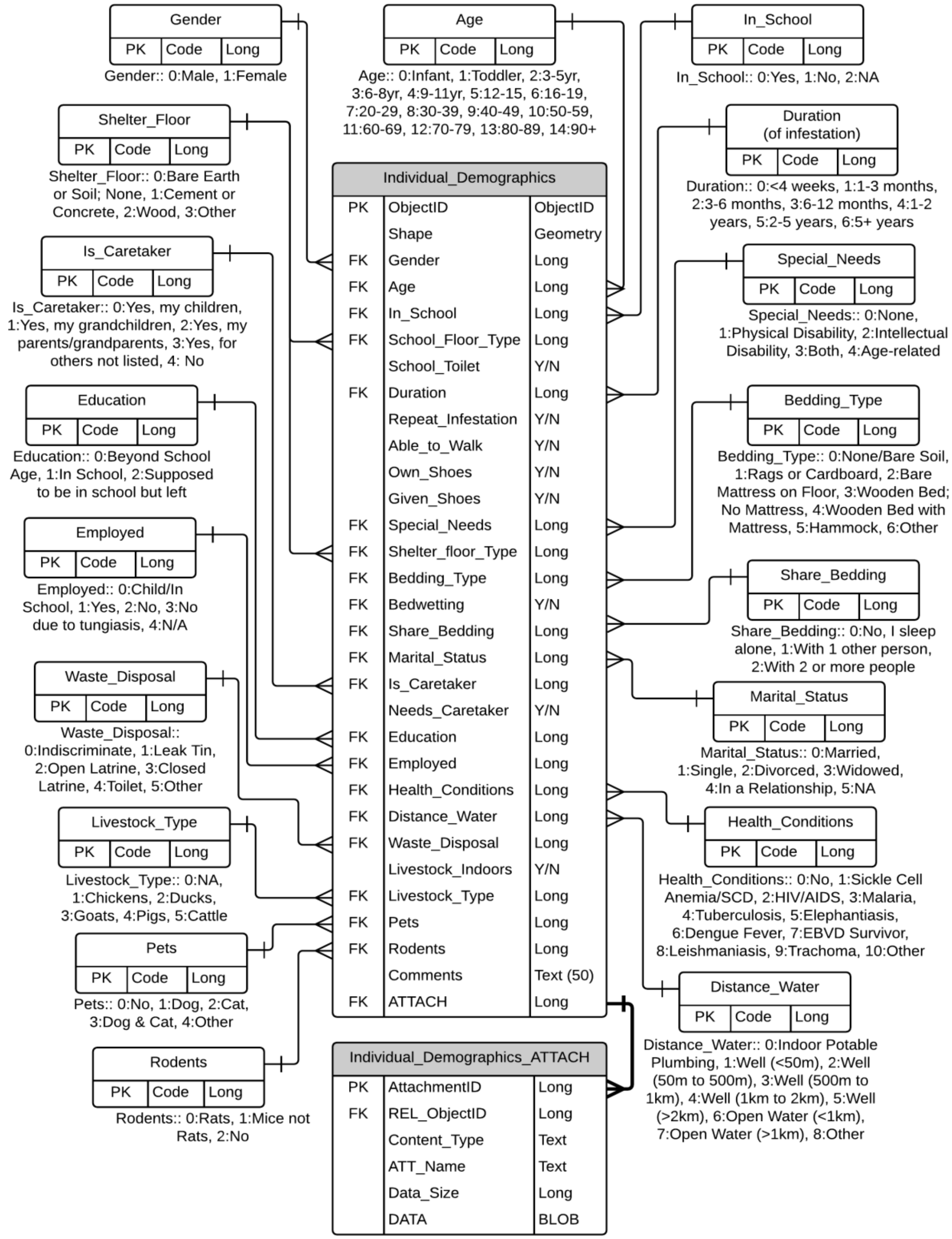


Figure 14 Individual_Demographics ERD

The *Service_Area* table is not relational, and only has six fields. This table enables service organizations to enter their geographic coverage areas to better identify locations that may be underserved by locally-operating CBOs. Table 7 defines the fields and data types for the *Service_Area* table.

Table 7 Fields and Data Types of the *Service_Area* table

Field Name	Data Type
ObjectID	ObjectID/Long Integer
Shape	Geometry (polygon)
Organization_Name	Text (50)
Contact_Name	Text (50)
Mailing_Address	Text (50)
Telephone	Text (50)
email	Text (50)
Website	Text (50)
Comments	Text (250)

Unlike the CFEP, the Tungiasis eLibrary ERD diagram is simple. Except for subtype tables (in the form of coded domains), the only feature class in the database is the article table, visualized as points. This flat file design is made possible by Esri's subtypes and domains, so the geodatabase needs only contain one table. Because attachments are enabled in the database, a separate SQL table is generated when the relationship is created. The main table is the *Tungiasis_elibrary*, discussed in detail in Chapter 4, Application Development. The three domains created in ArcMap are *Country*, *Article_Source*, and *Article_Focus*, and are used to organize and query the collected articles. The one-to-many relationships are supported in the latest version of Web AppBuilder (many-to-many relationships are not) and save space in the main dataset by recording single- or double-digit numbers in the table instead of textually-longer descriptions. The purposes of the *Country*, *Article_Source*, and *Article_Focus* domains are described in detail in Section 4.6 of the Application Development chapter, and the data collected is discussed at length throughout the rest of the thesis. Figure 16 shows the ERD representing the Tungiasis eLibrary database.

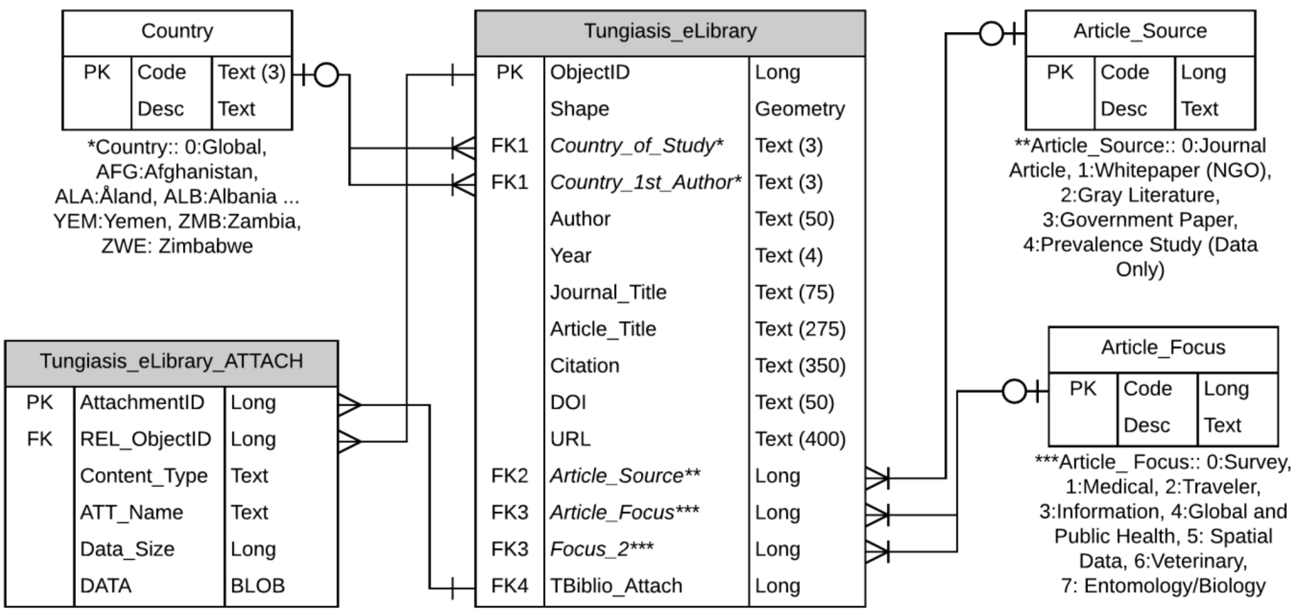


Figure 15 Entity-relationship diagram representing the Tungiasis eLibrary

3.3. Web GIS and Required Client Technology

Web GIS can be loosely defined as GIS or a GIS application that runs within a browser window (Jones and Purves 2008, Fu and Sun 2010). Generally, an internet connection is required. Making an application that can be used in a web browser eliminates the need to use device-specific software development kits (SDKs), instead producing a product that with few exceptions functions the same across multiple connected and mobile devices. With the near-universal adoption of JavaScript as a browser scripting language most websites use it along with HTML and cascading style sheets (CSS) and do not require additional plug ins (Flanagan 2011). Esri's ArcGIS API for JavaScript has effectively replaced the ArcGIS API for Silverlight, building rich interactive web mapping applications that can be quickly and easily produced for a variety of uses. Extending the API is Esri's WAB, which provides a graphical programming interface for individuals who might not have previous coding experience. This was one reason why WAB was selected for this project.

Web GIS was chosen instead of a mobile SDK for the following reasons. First, as of 2016, there are only two reliable mobile SDKs provided by Esri, one for Android and the other for iOS. Because mobile devices outside of the United States might not conform to the most recent Android or iOS firmware and software versions—or even be classified as an Android or iOS device—the mobile SDKs should be avoided for a project intended for a global audience. Web GIS provides a platform that any connected or mobile device with a browser can access. Had the author made the decision to develop a mobile solution, further GIS courses (namely SSI's Mobile GIS) would have been required. Additionally, the author did not want to have to develop for two platforms. Rather than need to learn two separate SDKs and create developer accounts for Apple's App Store and Android Apps on Google Play, the author decided to use a browser-based GIS solution as a one-stop option for connected use. The second reason for the selection of web GIS versus a standalone mobile app was the concept of collaboration. The author did not want the choice of mobile device to preclude any individual's or organization's involvement in the project or in data collection. Both the CFEP and Tungiasis eLibrary were built upon the idea of VGI, or data created from collaboration. By using web GIS as the technology for these apps, users can employ computers, tablets, and mobile devices to interact with the GIS provided a device has an internet browser.

Chapter 3 discussed the technology used to develop the CFEP and Tungiasis eLibrary apps. Several entity-relationship diagrams were constructed that illustrate the structure of the applications' back-end geospatial and flat-file database structure. Lastly, the selection of web GIS versus mobile GIS was justified and required client technology was described. Chapter 4 describes application development for both the CFEP and the eLibrary.

Chapter 4 Application Development Chapter

Chapter 4 presents the development of the CFEP and Tungiasis eLibrary applications. Section 4.1 discusses work performed in ArcMap leading up to publishing map and feature services. Section 4.2 describes the activities performed using AGOL, including its requirements for access, the differences between organizational and private account types, the process of authoring web maps and options for sharing them. Section 4.3 discusses the third phase of application development, the use of WAB to configure app behavior and functionality. Section 4.4 describes the supporting and VGI layers for the CFEP, and section 4.5 does the same for the Tungiasis eLibrary

4.1. Phase 1: ArcMap

Both the CFEP and the Tungiasis eLibrary were developed entirely with Esri software and services. ArcMap version 10.3.1 was used for each app to deploy an enterprise geodatabase consisting of both supporting data and mobile-editable feature classes which are shared as Map and Feature Services published using the REST protocol. These services are consumed in an AGOL web map where popups and behavior were modified. Esri's WAB was used to develop the application's graphical user interface (GUI) and add value with built-in widgets to create engagement with the AGOL web map it references. Widgets used to tailor the two apps include Legend, Layer List, Basemap Gallery, Measure, Help/Info, Edit, Query, Chart, Select & Export, Bookmark, Analysis, and Attribute Table. The workflow for producing the web mapping applications is visualized in Figure 16.

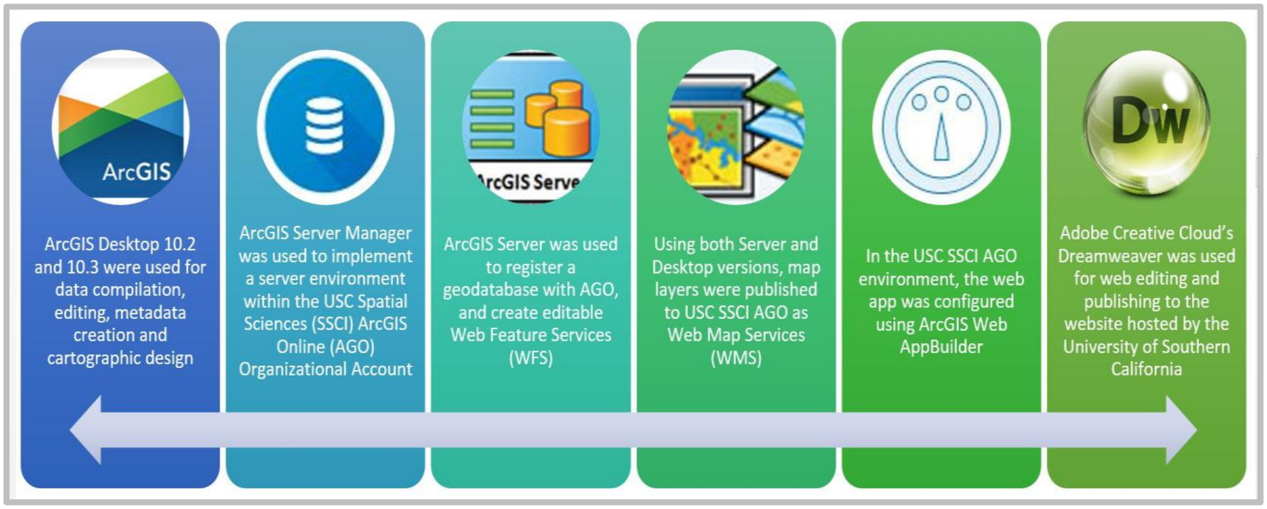


Figure 16 Esri-based workflow to produce web mapping applications

4.1.1. Publishing Services in ArcMap

Each app started with an ArcMap map document, referred to here as an MXD, which is the Esri map document file extension (.mxd). Within ArcMap, desired data layers are added to the MXD, where decisions about cartography, visible extent, labeling, and time-enabled layers are made. It is important to re-project all data to be published into the Web Mercator Auxiliary Sphere projection to prevent the web map from having to project data on the fly, which is resource-intensive. Services are published by choosing File > Share As > Service, which opens the Service Editor window. On the General tab, the Service Name, Connection, Type of Server and Type of Service are listed. The default type of service is Map Service and the box next to "Start service immediately" is checked. On the Parameters tab, it is wise to document the location of the Original Document so that it can be found at a later time. This is also where the maximum number of records returned by the server can be increased. The Capabilities tab is where specific map capabilities and functionalities are turned on and off. Mapping is always enabled. Checking the WMS and WFS boxes ensures that other apps designed to consume that format can do so. Feature Access must be checked for the application to allow editing or addition of data to a hosted database. If the “KML” box checked, cartographic symbology must adhere to the KML standard. Figure 17 shows the Capabilities tab of the Service Editor window for the Tungiasis eLibrary. The *Mapping* subsection of the Capabilities tab is where REST and SOAP URLs are displayed and allows developers to select which operations are allowed. The three checkboxes are “Data,” “Map,” and “Query.” If a REST service endpoint has “Query” enabled, users can easily view and download the data regardless of which fields are turned on or off in the web map and web app. It is wise to be cognizant of this when working with sensitive data. Additionally, the *Mapping* subsection allows the publisher to manage workspaces for dynamic

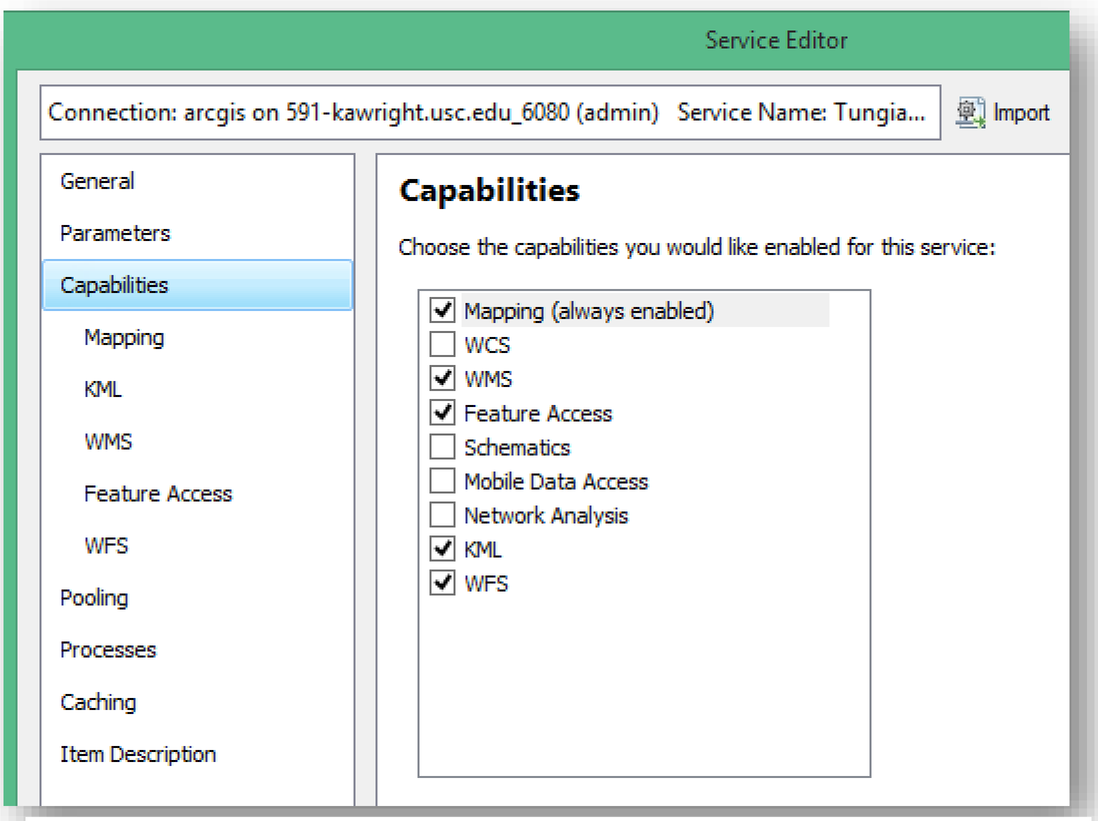


Figure 17 The Capabilities Tab of the Service Editor window

layers if per-request modification of layer order and symbology is permitted. The *KML* subsection provides the publisher several options about how the data is exported to KML. The *WMS* subsection provides a SOAP URL for the WMS Service and allows the publisher to select operations that are allowed on the data, and provides the opportunity to add spatial reference systems beyond the standard Web Mercator Auxiliary Sphere projection.

The *Feature Access* subsection of the Capabilities tab is very important for developers creating apps that enable data editing and creation (i.e. VGI apps). The REST and SOAP URLs for the Feature Service are listed and there are five checkboxes representing operations allowed. It is considered best practice to store this information in development documentation. The five are “Create,” “Delete,” “Query,” “Sync,” and “Update.” For both the CFEP and Tungiasis eLibrary applications the author elected to un-check the “Delete” checkbox to prevent accidental or intentional deletion of features, sabotage, or overall mischief since this service is open to the public. While it would still be possible to edit each feature, and move its geometry (the “Allow geometry updates” checkbox under Feature Access Properties in the Service Editor permits the editing of geometry), features cannot be completely deleted. Also important to consider when publishing Feature Services is that by default only 1000 features are loaded when the Service is called. Because a Map Service is functionally an image of data, it is easily cached on the server and is returned to the user with little performance consideration. On the contrary, to load a Feature Service requires significantly more system resources as the Feature Service actually queries the underlying data each time it is called to return all the records of all the features loaded. The number of features that load when the service is called can be increased from 1000 to any number on the *Feature Access* subsection of the Capabilities Tab.

The last subsection of the Capabilities tab is *WFS*. The SOAP URL for the WFS Service is listed, with other properties that affect service behavior when a WFS connection is made. It should be noted here that if a layer is time-enabled, a *Time* subsection appears in this list giving the publisher control over the time frame, time advancement speed, and if the visualization should begin on-load or on-click. A time-enabled service was published for the Tungiasis eLibrary, but it was not relevant to the collected data, so it was removed from the end application. The Pooling, Processes, and Caching tabs in the Service Editor did not apply to this project, but the last tab—Item Description—requires attention each time a service is published.

The Item Description tab builds the metadata that will accompany the map or feature service. It provides the text to fill the Item Description webpage that fronts each service endpoint or web map. Fields include “Summary,” “Tags,” “Description,” “Access and Use Constraints,” and “Credits.” As with the REST endpoints, it is wise to store this text in development documentation. Figure 18 shows the Item Description tab in the Service Editor for the *Tungiasis_eLibrary* Feature Service.

Once all tabs in the Service Editor have been addressed, it is time to run the Analyze tool to reveal what actions must be taken prior to publishing the service. Errors, Warnings, and Messages of varying severity either completely prohibit the publication of the service or advise the publisher to perform some action to improve its behavior. The boxes checked in the Capabilities tab of the Service Editor have direct impacts on what will be deemed unacceptable by the Analyze tool. For example, Esri has exciting and dynamic symbology available, but KML does not support those symbols. Because a major goal of this project is for people without access to expensive GIS software to be able to download these datasets and use them, map symbols were simplified so that layers could easily be imported to Google Maps and Google Earth.

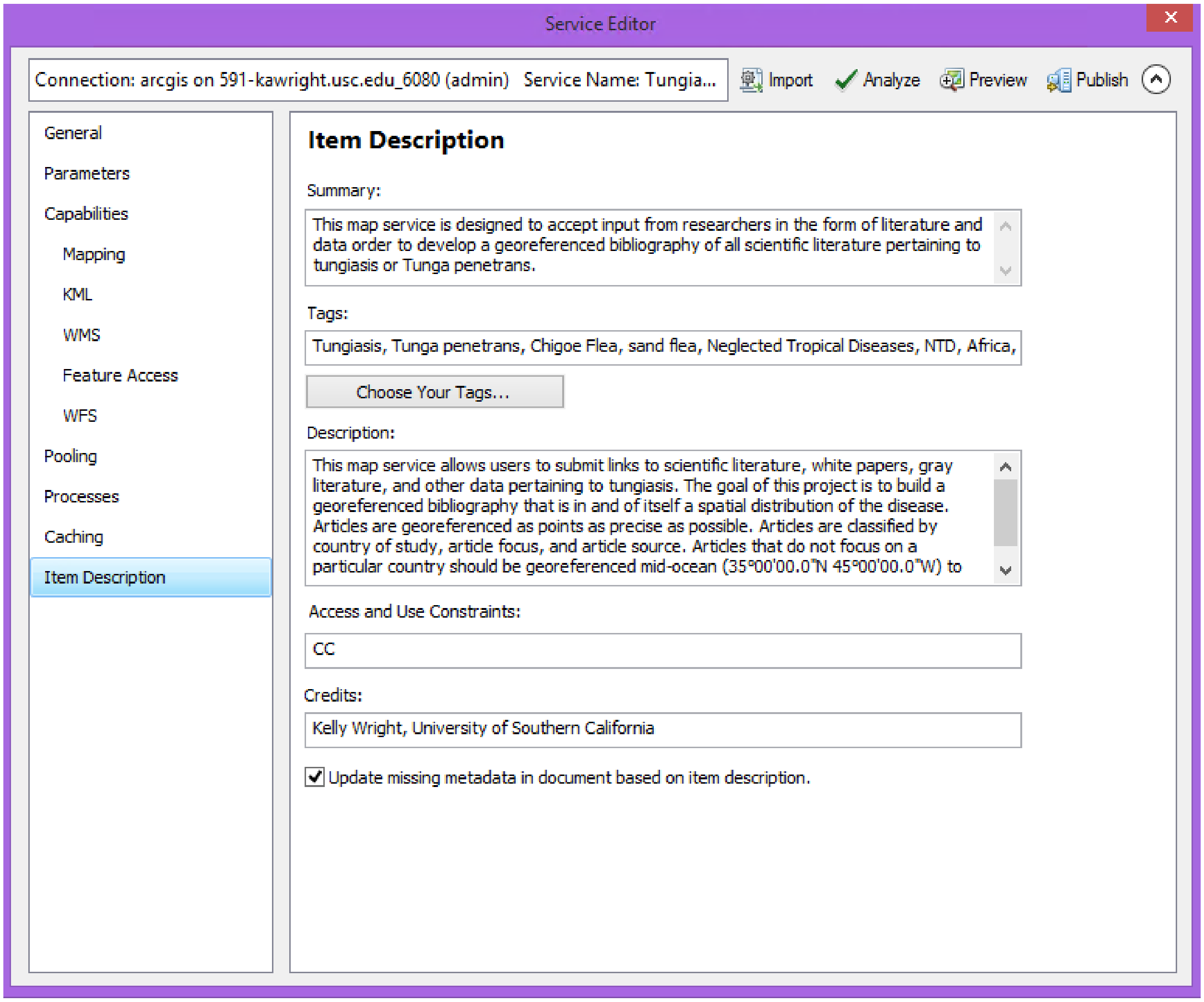


Figure 18 *Tungiasis_eLibrary* Feature Service Item Description

Another common error preventing publication involves Esri's basemaps. Esri basemaps must be stripped from the MXD prior to publishing since a web map and/or web accesses Esri basemap services hosted on AGOL. While it is fortunate that Esri has provided this service to its AGOL users, this makes working with the data prior to publishing in ArcMap very difficult. It also means that every time the source map document is opened, one must add a basemap to gain context or landmarks. This results in MXDs that are without context, often blank with only points, lines or polygons drawn with no reference to location or scale. It would be advantageous if future workflows to publish services could become “smart” enough to automatically exclude a basemap when publishing.

Another common error relates to visible extent. It is discouraged to have a layer display at all scales; maximum and minimum extent visibility settings are recommended. While it might be feasible to have a national boundary visible at a global scale, there is no reason to show *x,y* coordinates at that scale. While the Service Editor will not completely prohibit service publication without a visible extent range, it is highly recommended to use one. Also required is an Item Description as discussed earlier, unless a layer already had a description. If so, the layer’s summary and description are used to populate fields on the Item Description tab. Cartographically, layer transparency is not supported or must be changed to adhere to AGOL transparency settings. Some fill symbols in ArcMap do not carry over to AGOL, and fonts and/or icons must be true-type font to display correctly on the web map and apps.

Once all errors have been addressed or marked as exceptions in the Analyze wizard, the publisher clicks Publish to create or update the service. Publishing the service creates a REST service endpoint for consumption in a web map or other web GIS. Several REST endpoints were created for the CFEP and Tungiasis eLibrary applications. Appendix A lists all REST service endpoints for all Map and Feature Services consumed in the CFEP and Tungiasis eLibrary.

Because the CFEP was developed prior to the eLibrary, the decisions made when publishing services changed as the author’s experience increased. The case of the CFEP Data Discovery Map Service illustrates two lessons learned while developing these applications. Lesson number one: The MXD should only include layers that will be published to the map or feature service. In the case of the *Chigoe_Flea_Eradication_Data_Discovery* Map Service, the author added twenty-two layers to the MXD before publishing. One of those layers was a DEM and another a hillshade raster. Including multiple layers and large raster files in the same service is not an economic use of time or resources.

Every time updates were made to the data or cartography, all twenty-two layers in the service has to be re-published, which took a significant amount of time. This also introduced the risk of losing all the data if a software failure occurred mid-publish. Table 8 lists the layers and tables in the CFEP Data Discovery Map Service. Instead of publishing all of these together, the layers in the MXDs were reduced to one or two per service to speed up the publishing process and also to make those layers usable by more than one app without forcing unwanted data to load. Currently, it is considered good practice is to keep separate MXDs for separate layers or services published. At present, there are several MXDs per application that are published as several different services that can be consumed by multiple maps and apps.

Instead of storing tables in a map service, the best practice is to join a given table to a features in ArcMap, export the joined tables as a single feature class, and publish a map service using the feature class instead. In the case of this project tables are hosted; that is, they reside on the same server that hosts the CFEP and eLibrary VGI datasets, and are called by AGOL as-needed. These were data-only tables obtained during the data discovery portion of the CFEP development, that did not contain Geometry fields, so it was necessary to join them to the various boundary datasets collected for the project. This resulted in what appeared to be duplication of services and tables shown in Table 8.

Table 8 CFEP Data Discovery Map Service Layers and Tables

Water Point Mapping – Embu, Kwale, Turkana, Isiolo Counties
Primary Schools Lacking Toilets
Kenya Primary Schools
Health Facilities
Smaller Towns in Kenya
All Towns in Kenya
County Boundaries - 2014
2009 Administrative Boundaries • National Boundary – 2009 • Province Boundaries – 2009 • County Boundaries – 2009 • Former Districts – (2007-) 2009 • Former Locations – 2009 • Former Sub-Locations – 2009
Lakes – ILRI
Rivers – AFRICOVER
Sandy Soils – Extracted from Kenya Soil Survey
Soil Composition – Kenya Soil Survey 1982, 2002
1999 Census – Poverty Rate
Bare Areas – Derived from AFRICOVER
Urban Areas – Derived from AFRICOVER
Landcover Database – 2002 – Food and Agriculture Organization of the United Nations
Rainfall (in millimeters)
Kenya – Hillshade
Kenya – Shuttle Radar Topography Mission (DEM)
Data Only Table: Census Livestock
Data Only Table: Kenya Primary Schools
Data Only Table: Water Point Mapping
Data Only Table: Constituent densities1
Data Only Table: County Indicators
Data Only Table: Kenya Legend
Data Only Table: Census Vol II Q 11 Livestock

Services are published into a hierarchical file directory very similar to Windows Explorer, and can be customized to better organize or classify the layers being published. In the case of the CFEP, all layers were published in one directory labeled Chigoe_Flea_GIS. Figure 19 shows the resulting *Chigoe_Flea_GIS* REST services directory at http://591-

Figure 19 *Chigoe_Flea_GIS* REST Services Directory

kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS, which includes the *Chigoe_Flea_Eradication_Data_Discovery* Map Service discussed above.

This section discussed the work that must be performed in ArcMap prior to and including the publication of map and feature services, and mentioned best practices for selecting Map versus Feature Services. After publishing the map and feature services, an AGOL organizational account is used to create web maps and then share them as web apps using WAB. Section 4.2 discusses the second phase of app development, including work done using AGOL like creation of web maps, and web apps.

4.2. Phase 2: ArcGIS Online

In this thesis project, AGOL web maps were utilized to produce the maps consumed in the finished web mapping applications, as previously stated. According to Esri's AGOL product page, "ArcGIS Online is an online, collaborative web GIS that allows you to use, create, and share maps, scenes, apps, layers, analytics, and data" (Esri 2017a). AGOL's Living Atlas layers and extensive crowdsourced and in-house data layers enable users to create useful, compelling web maps without needing an ArcMap Desktop software installation. It should be noted that ArcMap, ArcGIS Pro, or ArcServer (ArcGIS Enterprise at the time of this writing) are required to publish map and feature services to AGOL. However, web maps themselves can be created and hosted on AGOL without purchasing ArcMap, if the data on the map is hosted on AGOL or obtained from another organization's REST services. Requirements for publication on AGOL and how much these items "cost" is covered in Section 4.2.1.

4.2.1. Requirements

AGOL is a cloud-based GIS that requires either a public account or an organizational account. “Org account” access is given to an organization that has “maintenance” included—that is, it pays annually for technical support through an Enterprise License Agreement (ELA), Master License Agreement (MLA) or education license. Org account subscriptions provide capabilities beyond a public account, which any person with an email address can create. For example, WAB is available exclusively to AGOL organizational and portal accounts, or by using WAB Developer Edition.

AGOL org accounts are provided with (and can purchase more) credits, a proprietary form of digital currency used on AGOL to access storage and higher functions. For example, excluding feature attachments, it costs 2.4 credits per 10 megabytes of data stored based on hourly calculations of storage per month (Esri 2017b). Feature attachments cost 1.2 credits per 1GB stored per month, and it costs 40 credits to geocode 1,000 addresses. Spatial analysis costs 1 credit per 1,000 features, and optimized routes, drive times, ad closest facility routing costs 0.5 credits per analysis. Esri has introduced many administrative tools and each tool is labeled with the approximate number of credits it will consume.

In short, AGOL provides thousands of ready-to-use maps through the Living Atlas, the ability to visualize either small or large amounts of data with web maps, access to spatial analytics tools, enables site administrators to control users’ access levels and content, provides a venue to sell apps in the ArcGIS Marketplace, and houses several industries’ worth of map and app templates catered to specific needs. Figure 20 shows the author’s AGOL “My Content” screen where all web maps, web layers, and web apps are stored and managed.

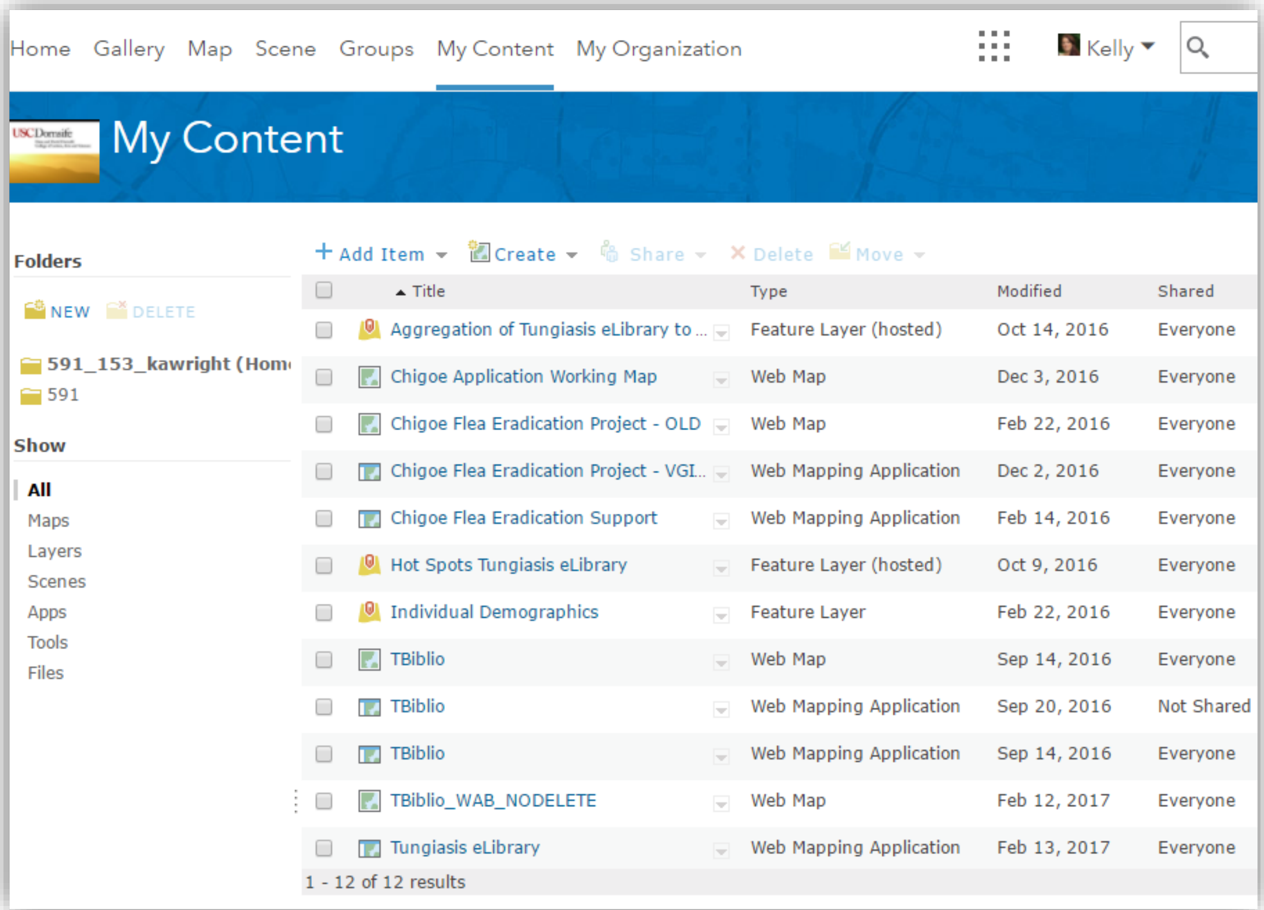


Figure 20 The Author's USC Org Account AGOL "My Content" page

4.2.2. Authoring Web Maps

AGOL web maps can be populated in one of two ways. The first does not require any ArcGIS desktop software and involves working with web layers, layers populated by the Living Atlas, or other AGOL data library layers. For data exploration and fast visualization of publicly-available data, this works well and requires little formal GIS training. However, if a user wishes to use their own data in their maps and apps, one of two things must occur. The first option is to store the data on AGOL, which consumes credits as discussed in the previous section. The second option is to publish an ArcMap map as a map or feature service as discussed above. After clicking "Add Item" on the My Content page, a New Web Map is selected. Data can be added using the Add button. Options include "Search for Layers," "Browse the Living Atlas for Layers," "Add Layer from Web," "Add Layer from File," and "Add Map Notes." In the case of the CFEP and Tungiasis eLibrary web maps, "web layer" was used. The REST Service Endpoint URL for the desired layer is input, and the layer appears on the map. Cartographic changes can be performed in the web map, but since symbology is included in the REST endpoint, oftentimes it is unnecessary. Changes include layer transparency, visibility range, placement within the legend, whether it is hidden within the legend, and labeling. The data can be visualized by changing its "Style," with options like "types (unique symbols)," "counts and amounts" by color and size, and "heat map." The data can be filtered (i.e. create a display query), and analysis can be performed within the web map (for a credit fee, as previously mentioned.) The web map that is consumed by WAB for the Tungiasis eLibrary is shown in Figure 21. The map is named *TBiblio_WAB_NODELETE* to remind the author not to delete it since without it the eLibrary does not function (the data is housed in a server and so is not deleted if the web map is deleted). The web map also provides a way for developers to customize map behaviors; for example, popups can be turned on or off, or customized to only display certain fields, use aliases, or specify certain colors and fonts for specific fields. If a layer is time enabled, the speed and duration of the visualization can be customized.

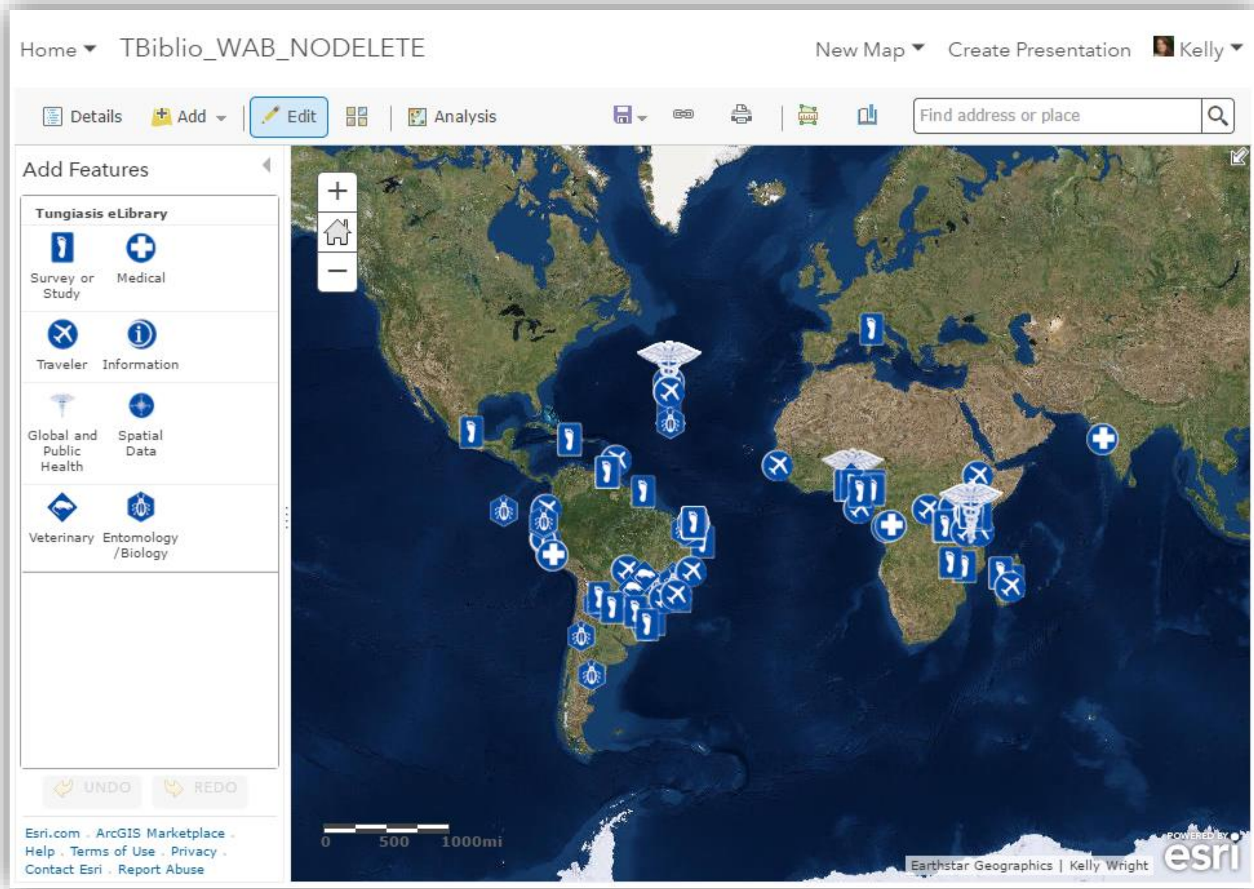


Figure 21 Web Map on AGOL for the Tungiasis eLibrary

It is important to address the Web Mercator Auxiliary Sphere projection used ubiquitously in web mapping. The persistence of the use of the Web Mercator projection can be explained by this: “This solution may have been a convenient choice made by someone, and the online mapping systems designed with web Mercator became popular enough to become the standard to which everyone else conformed” (Battersby et al. 2014). Much research in projections has been undertaken in the last century, which indicates that the Mercator projection, isn’t the best choice. Regardless, the grid structure of Web Mercator and its ability to neatly fit into a square tile (by removing latitudes in excess of 85 degrees) have contributed to it becoming the de facto industry standard. Few web mapping applications use a different projection.

4.2.3. Sharing the Web Map

Once a web map has been customized to the satisfaction of the publisher, it must be shared with either the public or appropriate groups. If a web map is not shared with the public, any application consuming that map will not function. After saving the map and giving it a name, developers click the Share button, which in AGOL looks like a “link” or “URL” icon at the top of the screen. When that button is clicked, a dialog box appears giving the publisher the option to share with Everyone (public), no one (by unchecking all boxes), or members of groups to whom the publisher belongs or has created. A shortened link to the web map is also included in addition to Facebook and Twitter share buttons. Additionally, developers can choose to embed the map in a website or create a web app. When the “Embed in Website” button is clicked, another dialog box appears. This window provides the publisher opportunities to change options to display on the map (like the Zoom controls, the Home button, Basemap Selector, Scale Bar, Legend, or Location Search), change the display size of the map, choose a light or dark theme, and add symbols and create popups for those symbols. Based on the publisher’s choices HTML code is generated that can be copied and pasted into a web page. When the publisher clicks on the Create a Web App button, the Create a New Web App dialog box appears. The different options for creating a web app are covered in Section 4.3.

4.3. Phase 3: Web AppBuilder

An AGOL organizational account is required to access the WAB interface. As of March 2017, WAB is at version 2.4; at the time of the CFEP and eLibrary app development Version 2.1

was used. At this version, WAB uses ArcGIS API for JavaScript version 3.x, despite the recent release of the 4.x API. WAB provides out-of-box solutions to web GIS app needs, but alternatively, WAB Developer Edition provides the WAB experience with even greater capability to customize theme and behavior, and an API to design new widgets.

AGOL public accounts have fewer options when creating a web app than an org account or WAB Developer Edition. After choosing "Create a web app" when sharing a web map, a popup appears like Figures 22 and 23 below. The top image is from the author's public account (kawright@gmail.com). The bottom image is from the author's USC SSI Organizational account. Note the Web AppBuilder Tab visible in that image.

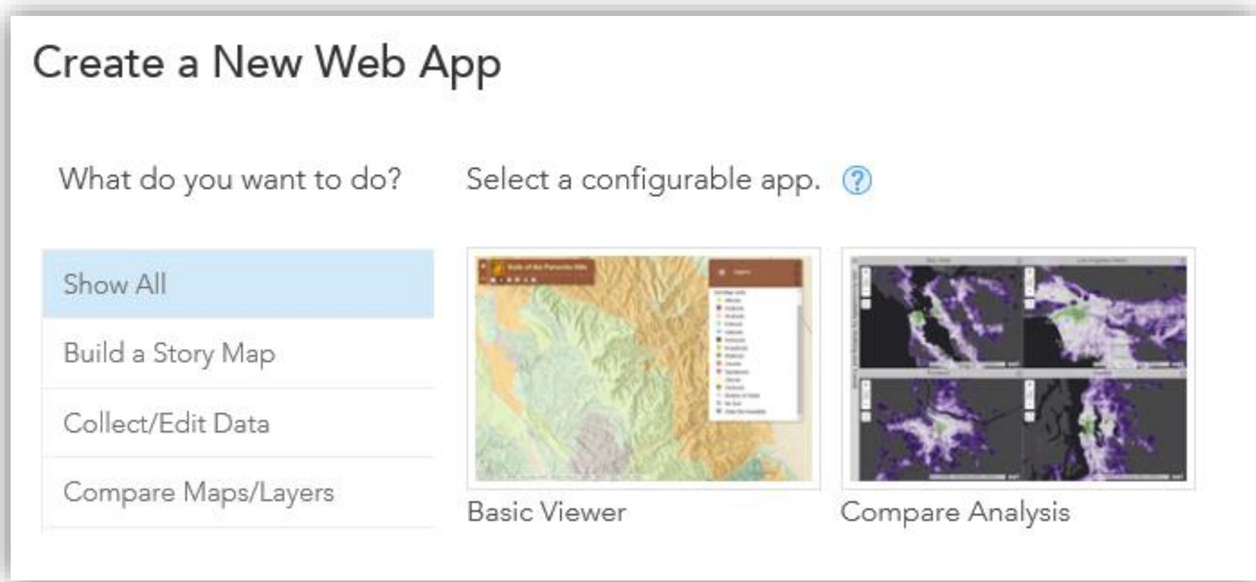


Figure 22 AGOL Public Account Web App Options

The publicly-available configurable apps are excellent. The choice to use WAB was driven by availability and ease of access through the USC Spatial Science Institute's organizational account rather than a real need for something better than the standard templates.

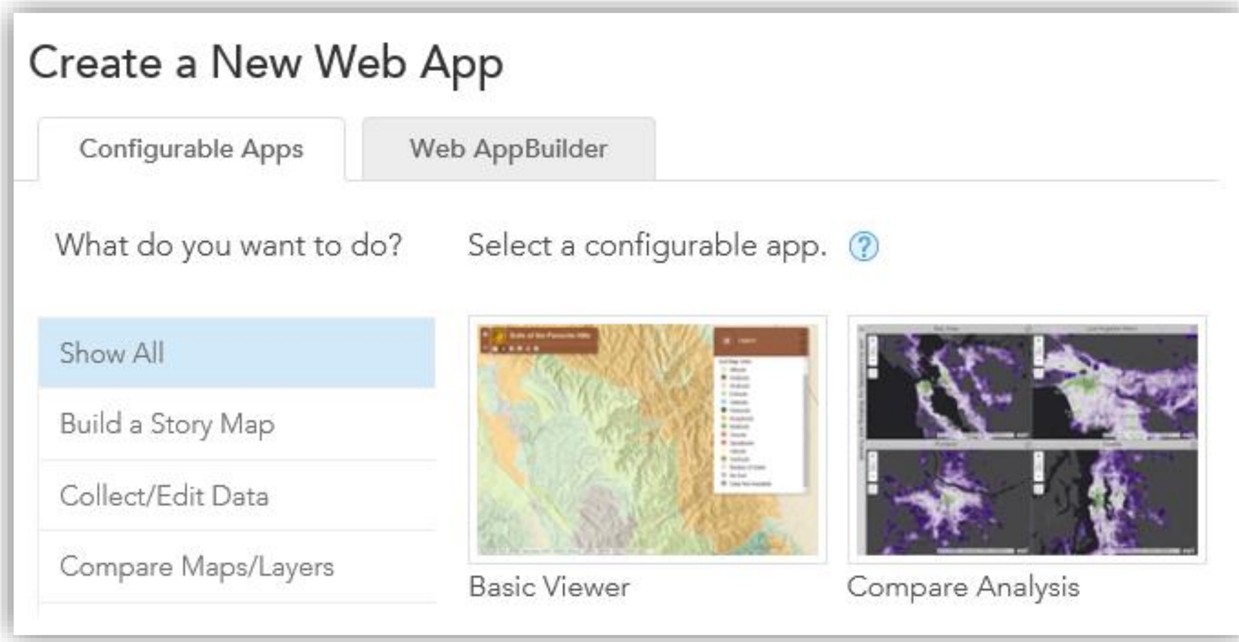


Figure 23 AGOL Org Account Web App Options

These configurable apps can be readily downloaded to a local machine, customized with the ArcGIS API for JavaScript, then directly uploaded either to AGOL or another web server. While WAB is a fantastic development tool, it is only available with a related organizational account. Thus, for either the CFEP or the eLibrary to continue beyond this thesis project, they must be adopted by an agency or organization that has the resources to pay for Esri software annual maintenance. Fortunately, in general, the web maps that feed WAB can be made publicly available and thus can be freely consumed by other users in third party web apps.

Once the WAB tab is selected, a dialog box appears prompting the publisher to enter a title, tags, and summary for the app. The title and tags are imported automatically from the web map's Item Description but can be edited here. Once the requisite information has been entered and the box checked to share the app in the same way as the web map, the Get Started button can be clicked and WAB for ArcGIS opens in the browser. The next section describes using the WAB interface to develop applications.

4.3.1. Configuring Apps Using WAB

The WAB workspace exists in a browser. The Esri WAB Devloper Edition is a separate, local machine software install, but this was not required in this project. The top bar of the browser window has a Home menu that contains links for navigation from WAB to other parts of AGOL, such as Gallery, Map, Scene, Groups, My Content, and My Organization. Unfortunately, these links do not open in a separate browser window. To the right of the Home button are the WAB logo and App Title (entered in the previous step). Lastly, the AGOL user's name heads a drop-down menu providing links to Community and Forums, My Esri, and Training, also listing options to switch accounts, open a help file, or sign out of AGOL. Beneath the top banner the browser shows the map on the right and a panel containing four tabs on the left. The four tabs are Theme, Map, Widget and Attribute. Figure 24 shows the WAB developer interface when editing the Tungiasis eLibrary app.

The Theme Tab shows the eight themes available for immediate use. Themes are templates of appearance and behavior, specifically color and layout. The themes are customizable using the ArcGIS API for JavaScript version 3.x in Developer Edition or if downloading a template for editing in an HTML editor like Dreamweaver or Notepad++. Out-of-box (OOB) options were used in the app development phases of this thesis project. WAB's OOB themes include Billboard, Box, Dart, Foldable, Jewelry Box, Launchpad, Plateau and Tab. The Launchpad theme was selected for the Tungiasis eLibrary, and the Foldable theme for the CFEP. Also on the Theme tab is a Style selector, which enables developers to select from pre-set color schemes or set a custom color scheme for the app. A third section in the Theme tab offers

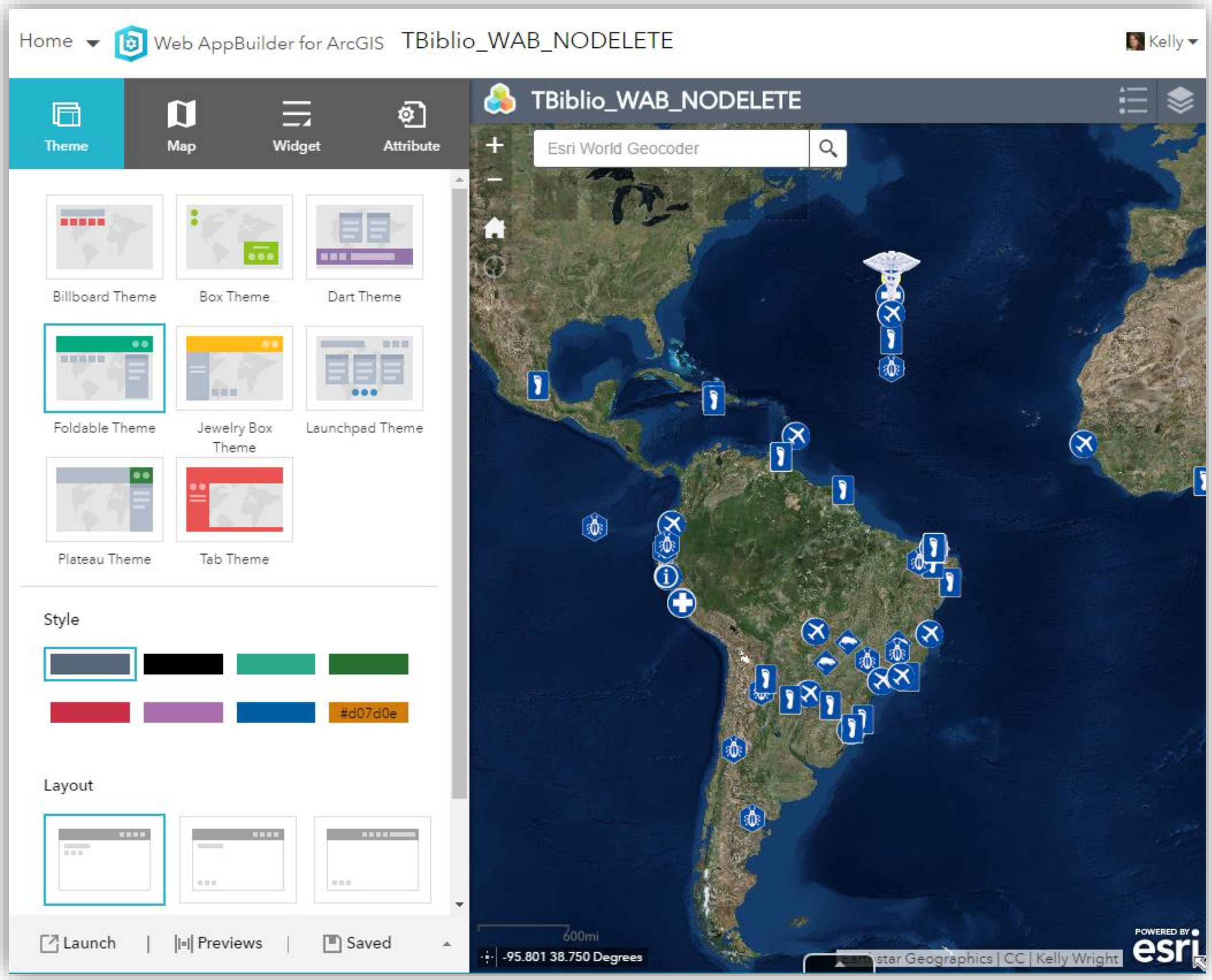


Figure 24 The WAB developer interface

various layouts—that is, where icons and widgets are placed in the app. The Map tab lists and previews the web map selected to be consumed in the app. The map can be modified here, as well as the map's initial extent and visible scales. These customizations can also be made within ArcMap or AGOL when creating a web map. The Attribute tab enables developers to brand their apps with a logo, title, and subtitle, or include a URL to a website. These modifications appear at the top of the app. Combined with the Style selection on the Theme tab, these changes to the Attribute tab fully customize the app's appearance.

4.3.2. Widgets

Widgets are in-app tools that perform various map- and data-related functions as part of the user experience. Prior to WAB's release, map widgets had to be individually coded using the ArcGIS API for JavaScript, and/or other programming languages. Widgets in WAB have already been coded to work within the parameters of the WAB interface, and so require zero additional programming. As with all parts of WAB, widgets can be further customized or developed anew in either the Developer Edition or within a code editor using the API. Since WAB is capable of both 2D and 3D (Scene) visualization, certain widgets only operate when the corresponding data type is present. Figure 25 shows 2D widgets available as of March 2017. Widgets are classified as “off-panel,” “in-panel,” or “on-screen,” depending on the theme. In-panel widgets are included in the “panel” of an app theme, while on-screen widgets are displayed in the map area. Off-panel widgets show up in a theme's alternate widget controller. For example, the Foldable theme's widget controller is in the bar at the top of the map, while the Launch Pad theme's widget controller is at the base of the map.

4.3.2.1. CFEP widgets

In the CFEP, several WAB widgets have been tailored to illustrate the strengths of GIS for epidemiological research. The “Analysis” widget gives analytical power to the user by providing GIS software geoprocessing capabilities within a browser-based application. The four analysis tools included are the “Aggregate Points” geoprocessing tool, the “Calculate Density” tool, the “Create Buffers” tool, and the “Overlay Layers” tool. These widgets function when logged into the organizational account tied to the application (in this case USC Spatial Sciences Institute) and illustrate the flexibility of the web GIS platform and the benefits of the WAB API. The supporting data to which the analysis widget is applied are described in Section 4.5.1.

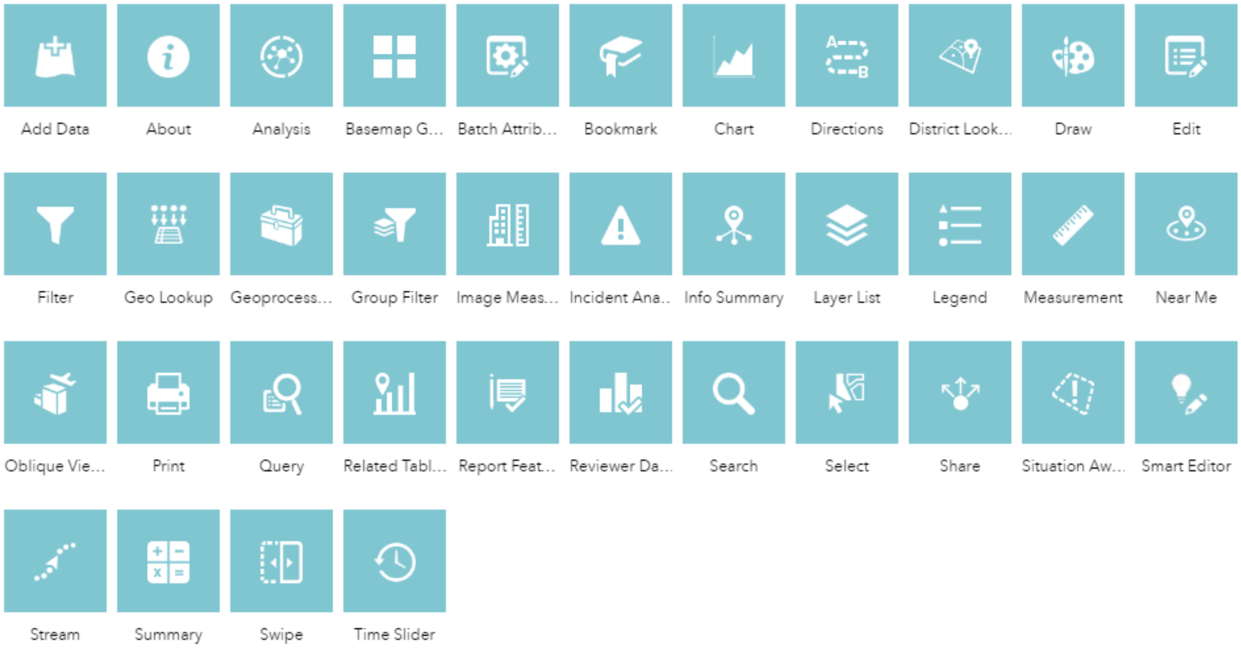


Figure 25 Widgets in WAB version 2.4

The "Query" widget houses multiple pre-set queries that demonstrate how data can be filtered to become information. The publisher builds SQL queries within the widget in the WAB widget setup dialog to query one or many layers of data or perform spatial queries as well. The queries in the CFEP are by no means exhaustive, just representative of the functionality of the Query widget. One query returns the locations of primary schools in Kenya that lack toilet facilities, while another allows users to locate areas where total annual rainfall is less than x millimeters. Users enter the value and then press the Execute button to see the results on the map. A third query shows areas where camels outnumber goats, using the 2009 Kenyan Ministry of Agriculture Livestock Census to demonstrate the differences in agricultural practice based on geography. A fourth query reveals the locations of schools where girls outnumber boys, and the last shows which of Kenya's primary schools have only one room.

Additional widgets used in the CFEP include the “Measure” widget, giving users the ability to take approximate line and areal measurements in kilometers, and the map controls Zoom, Home, Legend and Layer List. The “About” widget has been tailored to include detailed instructions for the CFEP’s use. Figure 26 shows the Analysis, Help, and Attribute Table widgets within the CFEP.

The author’s selection of web GIS and WAB for this thesis project was at first to support the provision of data discovery options to disparate groups dealing with tungiasis. As the project evolved, the use of web GIS was further justified by the inclusion of the VGI layers documenting individual patient demographics, pesticide treatment, and the drawing of aid organizations’ service areas. These VGI layers are discussed in greater detail in Section 4.5.2. These three layers are accessed through the “Contribute Data” widget, which is a tailored WAB “Edit” widget. This OOB widget was renamed to indicate its purpose, and the three feature services can be edited or new features added. When the widget is opened, the feature templates for the three layers can be selected to create or update existing features. Deletion of features is not permitted. By introducing VGI to the application the CFEP serves dual purposes: one, as a data-discovery app, and two, as a collaborative workspace where multiple disparate parties can collect the same data and store it in the same “location.”

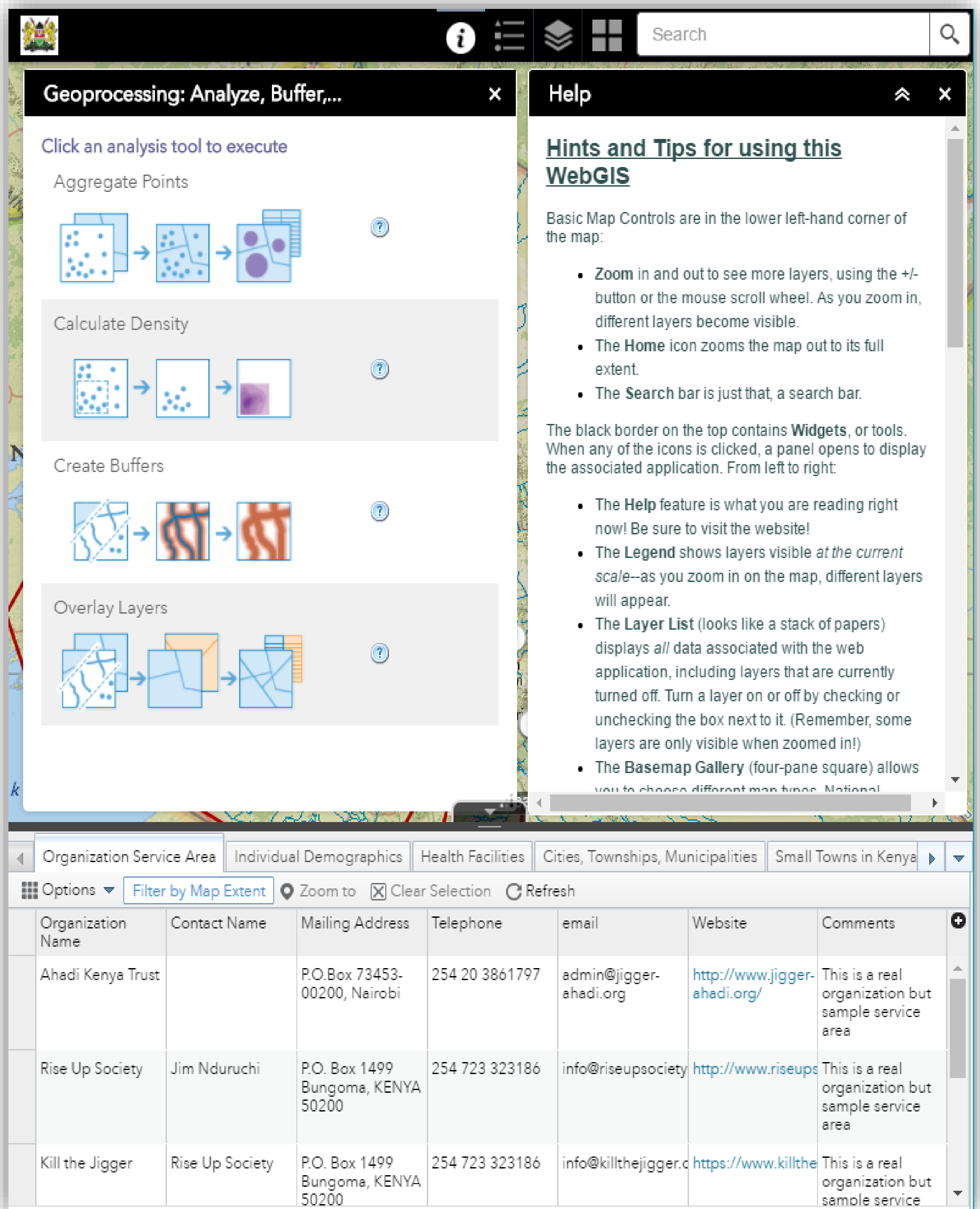


Figure 26 The Analysis, Help, and Attribute Table widgets in the CFEP

4.3.2.2. Tungiasis eLibrary Widgets

While the Tungiasis eLibrary application is thematically simpler than the CFEP, it utilizes more widgets. Documents are added to the eLibrary through the "Contribute Data" widget, a tailored "Smart Editor" widget using a popup form to record attributes. The Smart Editor widget enables the use of skip logic, or conditional logic, in the data collection form. It also provides the option to move or modify existing geometry, and the ability to require, disable or hide a field based on the values in other fields. Values can be pre-set across many fields on many layers to apply to each newly-created feature. Additionally, the widget opens in its own panel, not using a feature popup, and does not push changes to the database until the Save button is clicked. This widget is used to collect the data that populates the *Tungiasis_eLibrary* feature class.

After an article is georeferenced as a point on the map representing the study's location and symbolized according to its focus, a panel appears with several fields to be populated. The article's first author, home country of first author, journal title, article title, publication date, and Turabian citation are collected in the form. Some responses are drop-down, while others require textual input. If possible, the URL or DOI for the article is entered, and the database accepts attachments (requesting that the documents not be under copyright, or have a CC license). Attributes are searchable through multiple pre-set queries in a modified "Query" widget, entitled "Browse for Articles." The Browse for Articles widget provides users with pre-set queries that add meaning to the collected data. The Queries are listed in Table 9. A meta-analysis of the collected articles can be explored through additional analysis layers included in the "Layer List" and "Chart" widgets. Those layers are discussed in greater detail in later chapters. Several points of interest are stored in the "Bookmark" widget for user perusal. Data can be selected spatially in the “Select and Export” widget, which performs statistics on and creates layers of the selected data in addition to exporting data in comma-separated values (CSV), GeoJSON and Feature Collection data formats. A modified “Search” widget uses the eLibrary feature layer for full-text search in all fields of the database.

Table 9 WAB-built Queries in the Tungiasis eLibrary

Query	**Description**
First Author	This tool allows users to select an author’s name from a list. It only returns articles where the author is the first listed.
All Authors	Most like a library search, users can type in an author’s last name to search all authors affiliated with an article, provided its citation is available.
Country of Study	This tool allows users to select the country of study from a list.
Country of First Author	This tool allows users to select the first author’s affiliated country from a list
Journal	This tool allows users to select a Journal’s name from a list. It will only return records that have an affiliated Journal Title.
Type of Literature	This tool allows users to filter articles by their type: • Journal Article • Whitepaper (NGO) • Government Paper • Prevalence Study • Gray Literature
Study Country/Author Country Different	This query returns all articles whose first author lives in a different country than the study pertains to, except for articles of with “Global” emphasis.
Epidemiological Literature	This query returns all articles whose Primary or Secondary Focus is “Survey or Study”
Traveler Literature	This query returns all articles whose Primary or Secondary Focus is “Traveler”
Entomological/Biological Literature	This query returns all articles whose Primary or Secondary Focus is “Entomology/Biology”
Veterinary Literature	This query returns all articles whose Primary or Secondary Focus is “Veterinary”

4.3.3. Deploying the Apps

Once selections in the Theme, Map, Attribute and Widget tabs in the WAB interface have been finalized, it is time to launch the application. Below the tabbed panel are three buttons: Launch, Previews, and Save. Saving the application finalizes any changes made to the interface. The Previews button opens a tool in the browser window that shows what the app will look like on several common mobile devices. Figure 28 shows the Previews tool interface.

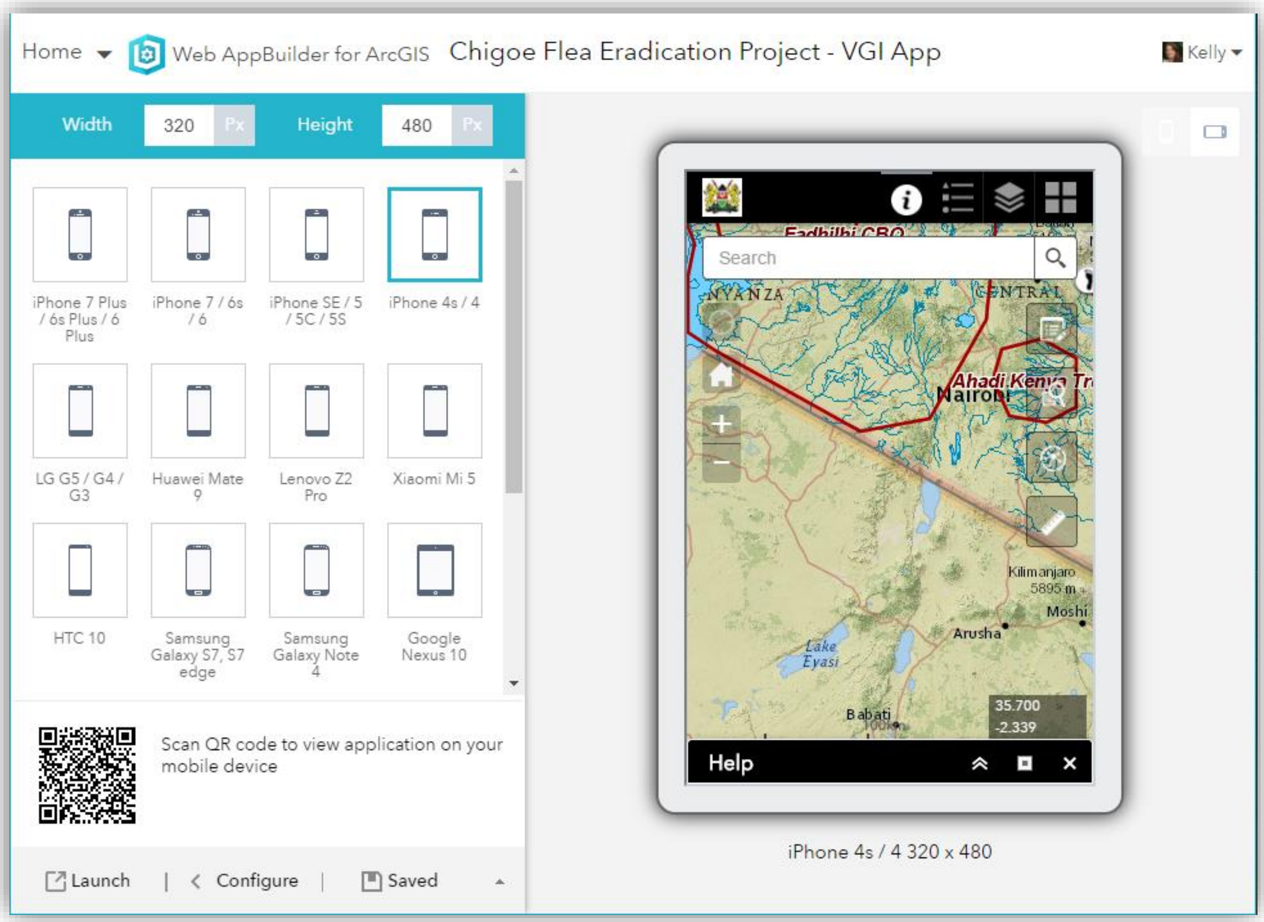


Figure 27 The Previews Tool in WAB

When all changes have been made to the app’s interface, the Launch button in the lower left-hand corner of the screen opens the completed app in a browser window complete with

URL. The last part of the URL is the unique app ID. This ID can be used to embed the app within a website, as was the case for both the CFEP and Tungiasis eLibrary. It is the tag that all browsers use to call the maps and apps from AGOL. Table 10 shows the web map and web app IDs for the CFEP and Tungiasis eLibrary.

Table 10 Web Map and Web App Unique IDs

Map or App	**Unique ID**
CFEP Web Map	8d5fdc98a63942edb4b4a3520e655659
CFEP App	4563a0de487046eb8c74eccfedc94ba0
eLibrary Web Map	d4f7356367a0485da951017e6691fdb9
eLibrary App	3f0a38ccd8c44ba7a6c4d58c4f24f6c8

4.4. CFEP: Data Layers

Kenya was selected as the study area to illustrate the efficacy of the web GIS interface to explore data in predicting *T. penetrans* hotspots and to provide a collaborative workspace for managing disparate humanitarian aid efforts. The geodatabase infrastructure can easily be updated to accommodate more WHO member states by adding primary school datasets and FLAU boundaries for other WHO member states. However, in the interest of prototyping applicability, only GIS data from Kenya were included in this thesis application.

4.4.1. Supporting Data Layers

Pre-existing data layers required for this research design include international and first-level administrative unit administrative boundary datasets (polygons), and primary schools (points). Rainfall isopleths and a digital elevation model (DEM) accompany a hydrology shapefile and land cover/land use dataset. Water access points are mapped at a very fine scale, but are not available for the entire study extent. Point datasets of towns, cities, and urban centers are accompanied by medical facilities/health centers. Malaria endemicity zones, a 2009 livestock census, and a 1999 Poverty Map complete the supporting datasets. These layers were imported to the CFEP web GIS to demonstrate the power of spatial analysis in predictive mapping of a vector-borne disease by enabling users to overlay known risk factors. The layers serve to represent GIS datasets that may be available from national governments that could be translated to other countries or diseases.

4.4.1.1. CFEP supporting data: primary schools

Primary schools were used in the CFEP because most national departments of education maintain school locations as part of record-keeping practices. If GIS data for a country exists, it is likely that some government body has produced datasets detailing school location and pertinent attributes, for maintenance and tracking of taxes if for no other reasons. Because rural areas are often not incorporated due to low population density, schools can be considered an analog for the centroid of communities when no other administrative boundaries exist. It is the theoretical likelihood of finding this data, combined with the larger issue of data conflation between differing administrative boundaries, that makes a school dataset ideal for this project.

Kenya's Ministry of Education maintains an internal School Mapping Database that is accessed through the Kenya Open Data Initiative (www.opendata.go.ke). While this is Kenya's authoritative dataset, the most recent survey performed was in 2007. The dataset is entitled Kenya Primary Schools and includes 26,197 primary schools. The Geolocation field contains complete x,y coordinate pairs within parentheses. School name, demographic employment data, number of pupils, public/private status, and sanitary waste disposal information are relevant for the CFEP, since schools without access to modern human waste disposal (i.e. toilets) or those with bare soil floors could be targeted for preventative treatment.

This data was prepared by downloading as a CSV file, saving it as an Excel workbook, and splitting the Geolocation field into two fields labeled LatY and LongX using Microsoft Excel's Text to Columns tool with commas as delimiters. Parentheses and additional spaces were removed using the Find and Replace tool. Reduction of the number of fields was considered if the dataset proved to be too cumbersome to run in an online environment, but the author decided to keep all datasets as unmodified as possible for ease of update in the future and to not remove attributes that users might find relevant during statistical analysis. Next, the Excel workbook was imported into ArcMap using the Excel to Table tool in ArcToolbox's Conversion toolset. Once the table was created, the *x*,*y* point data was displayed using the WGS 1984 geographic coordinate system (GCS). This produced a point event layer, which was exported as a feature class to the Tungiasis file geodatabase. The points were mapped in ArcMap and published to AGOL as a map service REST endpoint for consumption by the CFEP.

4.4.1.2. CFEP supporting data: weather, climate, and elevation

Unlike its landlocked sub-Saharan neighbors, Kenya's climate zones vary, mostly due to changes in elevation and proximity to large bodies of water. The updated world map of the Köppen-Geiger climate classification reveals that Kenya's unique topography plays a significant role in its temperature, humidity and soil moisture (Peel 2007). Its equatorial (Af), tropical savanna (Aw), warm desert (BWh), warm semi-arid (BSh), temperate oceanic (Cfb) and temperate Mediterranean (Csb) climates all support endemic populations of *T. penetrans*, which require warm, sandy, well-drained soils to reproduce. As an example, one tungiasis research study surveyed residents of one typical endemic area in Brazil for the presence of embedded sand fleas to better illustrate transmission dynamics of *T. penetrans*. The study found a statistically significant peak in parasite burden during the dry season, a conclusion important for developing control measures (Heukelbach et al. 2005). Applying this knowledge to any study area can help aid organizations calculate "when" is the greatest risk for tungiasis in addition to "where." Kenya has two distinct rainy seasons, a heavier one that begins in late April and extends through June, and a much shorter one in November and early December. Thus, the drier months are July through October, and January through March. Data in the form of monthly precipitation isopleths derived from years of weather station data can be used in conjunction with available digital elevation models (DEMs) to eliminate locations that are too moist for *T. penetrans* to flourish, such as wetlands and swamps.

Kenya's National Water Master Plan, developed with the aid of the Japanese International Cooperation Agency (JICA), includes the annual rainfall distribution in millimeters per year for Kenya. An undated digital elevation model (DEM) derived from a Shuttle Radar Topography Mission (SRTM) image is hosted by the World Resources Institute (WRI) and shows a shaded relief surface at 90-meter resolution. The 90m DEM was preferred over more recent 30m DEMs due to file size; because this was a prototype application that runs through a browser, load time became a more significant consideration than precision.

4.4.1.3. CFEP supporting data: land cover

Because *T. penetrans* requires dry, sandy soils to complete its life cycle, land cover data is valuable for determining areas of tungiasis hotspots. The Food and Agriculture Organization of the United Nations (FAO) in conjunction with the Kenyan Ministry of Environment and Natural Resources developed a multipurpose land cover database called Africover. This full resolution land cover was produced from visual interpretation of digitally enhanced high-resolution LANDSAT TM images using Bands 4, 3, and 2, acquired in 1995. The land cover classes were developed using the FAO/UNEP international standard land cover classification system, and despite the age of the dataset (published in 2002) is still considered authoritative by the Kenyan government.

4.4.1.4. CFEP supporting data: hydrology and water access points

Despite the accurate placement of rivers and streams on Esri basemaps, a rivers and streams dataset would allow users to calculate the distance people must walk to gain access to water. Since the flea's life cycle can be disrupted by wetting areas of open soil, settlements closer to water—even if not potable—are able to better manage *T. penetrans* outbreaks. Subsequently, a rivers and streams shapefile was obtained from Open Data Kenya. In addition to the hydrology shapefile, the repository contains several datasets pertaining to water access points (WAP) at a local scale; the CFEP displays one or two counties' worth of WAP derived from the Open Data Kenya repository to illustrate spatial analysis using these points to accurately produce WASH maps. Three districts of WAP were visualized in the CFEP. However, the author did not want to house the multitude of WAP datasets for the entire study areas due to the amount of storage space and server resources that would be consumed.

4.4.1.5. CFEP supporting data: towns and urban centers

The towns and urban centers dataset was digitized by and housed at the International Livestock Research Institute (ILRI). It shows the towns and urban centers in Kenya derived from the Kenya topographic sheets of scale 1:250,000 for northern Kenya and 1:50,000 for the rest of Kenya. There are approximately 1620 towns and urban centers captured in this layer. The towns have been classified into six categories: Municipality, Township/Town, Trading centre, Market centre, Lodges/camps, and (one) City (Nairobi). It was last updated in 2000. Much like the rivers and streams dataset in the CFEP, these cities feature classes can be used for spatial analysis to determine which geographic areas are at greatest risk for tungiasis as a function of distance from nearest town. To improve draw time and create more specific selection sets, the overall dataset was divided into two for cartographic display. Since Esri's basemaps dynamically redraw at each zoom level and include town and city names, it was ultimately decided to leave these layers in the app but be turned off by default. Spatial analysis can still be performed using this dataset without clogging the mapped area with town names in duplicate or triplicate.

4.4.1.6. CFEP supporting data: health centers in Kenya

This dataset was the result of a joint effort between Kenya Medical Research Institute (KEMRI), the Welcome Trust Collaborative Programme, Trypanosomiasis and Land Use in Africa (TALA) Research Group, Department of Zoology at the University of Oxford, the Kenya Ministry of Health and Oxford Centre for Tropical Medicine and Global. The point dataset plots the relative location of health service providers for Kenya and categorizes each location by type and supporting agency. Like other datasets obtained from Open Data Kenya, this was produced in 2007. Updates are expected in 2017 from a more recent government survey. One potential use of this dataset is to construct buffers around each point, revealing areas that may lack basic medical services and thus might require greater attention for tungiasis treatment and prevention measures.

4.4.1.7. CFEP supporting data: malaria endemicity

As an example of overlay and examining comorbidity of diseases, a layer of malaria endemicity data for Kenya was obtained from ILRI. This layer utilizes population data from 1989, 1997, and 1999 along with malaria infection rates to determine endemicity of districts within the country. This layer brought the issue of boundary fluidity to the author's attention; it does not correctly line up to any boundary dataset within the CFEP because of the discrepancies between district names and the years in which the data was collected and displayed. (This boundary-fluidity phenomenon is discussed later in Chapter 7.) Multiple online web portals house more up-to-date malaria data than this layer, much like the web mapping applications/data repositories for NTD prevalence data discussed in Chapter 2. This layer, while out-of-date, was convenient to include as a specific example of examining overlaid distribution and prevalence data for multiple diseases in order to develop better IC strategies that can be tailored to shared geographies.

4.4.1.8. CFEP supporting data: 2009 census and the Poverty Map

During development of the CFEP, the latest census data available from the National Bureau of Statistics in Kenya was from the 2009 census. Specifically, the CFEP included the Population by Sex, Household, Areas and Density data to try to recreate the 1999 Kenya Poverty Map developed by the ILRI, the Central Bureau of Statistics, and the Kenyan Ministry of Planning and National Development. The Poverty Map was published in 2001. Despite its age, it was also included in the CFEP for data exploration. Attributes of the Poverty Map included data about location (rural or urban), population per the 1999 population and housing census, an individual headcount of people living in poverty, poverty density, poverty rate (the proportion of people living below the poverty line), and the percentage gap to bridge for the poor to exceed the poverty line. Again, the purpose of a poverty layer is to use in overlay with other layers representing environmental and socioeconomic risk factors for tungiasis and other NTDs.

4.4.1.9. CFEP supporting data: livestock census

Kenya's 2009 census contained data about livestock population by type and district. This dataset is relevant to the CFEP for two reasons. One, this dataset provides an excellent example of the fluctuating boundary problem discussed in Chapter 7. Because the tabular dataset only contains data for districts as drawn when the data was collected (pre-2009), maps created by joining this table to a boundary spatial dataset cannot be accurately displayed. Figure 28 is a screenshot of the CFEP 2009 Livestock Census displayed as a dot density map and clearly reveals the gaps in data that result when a matching boundary dataset cannot be located. Each dot represents 875 animals, and species have different colored dots. The bright aqua dots represent camels. The northeastern portion of the country is desert and camels vastly outnumber other livestock. Bright green dots represent commercial chicken farms and are concentrated mostly around the capital city, Nairobi. Cattle are represented by red dots, and swine by blue dots. Donkeys, beehives, and goats are represented by dark green, yellow, and orange dots, respectively. The dataset was produced in 2009, but no boundary dataset could be located for this time frame, so the boundary feature class used to perform a join to the census data was from 2013, after many districts had been consolidated. Figure 28 also helps to illustrate the problem of comparing some types of data visually; a dot density map has been used here but there are areas of no data on the map, which indicates that care should be taken when drawing conclusions formed based on the census data.

As previously stated, one of the biggest risk factors to persistent tungiasis is sharing living quarters with livestock. A livestock study such as this—preferably at a finer scale—could help target efforts to educate the public about the flea's hosts and specific preventative measures that might be taken, as discussed in Chapter 1. Of great interest is the data about swine, as the possession of pigs has been found to be the single greatest risk factor to tungiasis in Uganda (Ugbomoiko et al. 2008). The 2009 Livestock Census data, although questionable, does reveal patterns throughout the country, and it is interesting from a geographer's perspective to note the

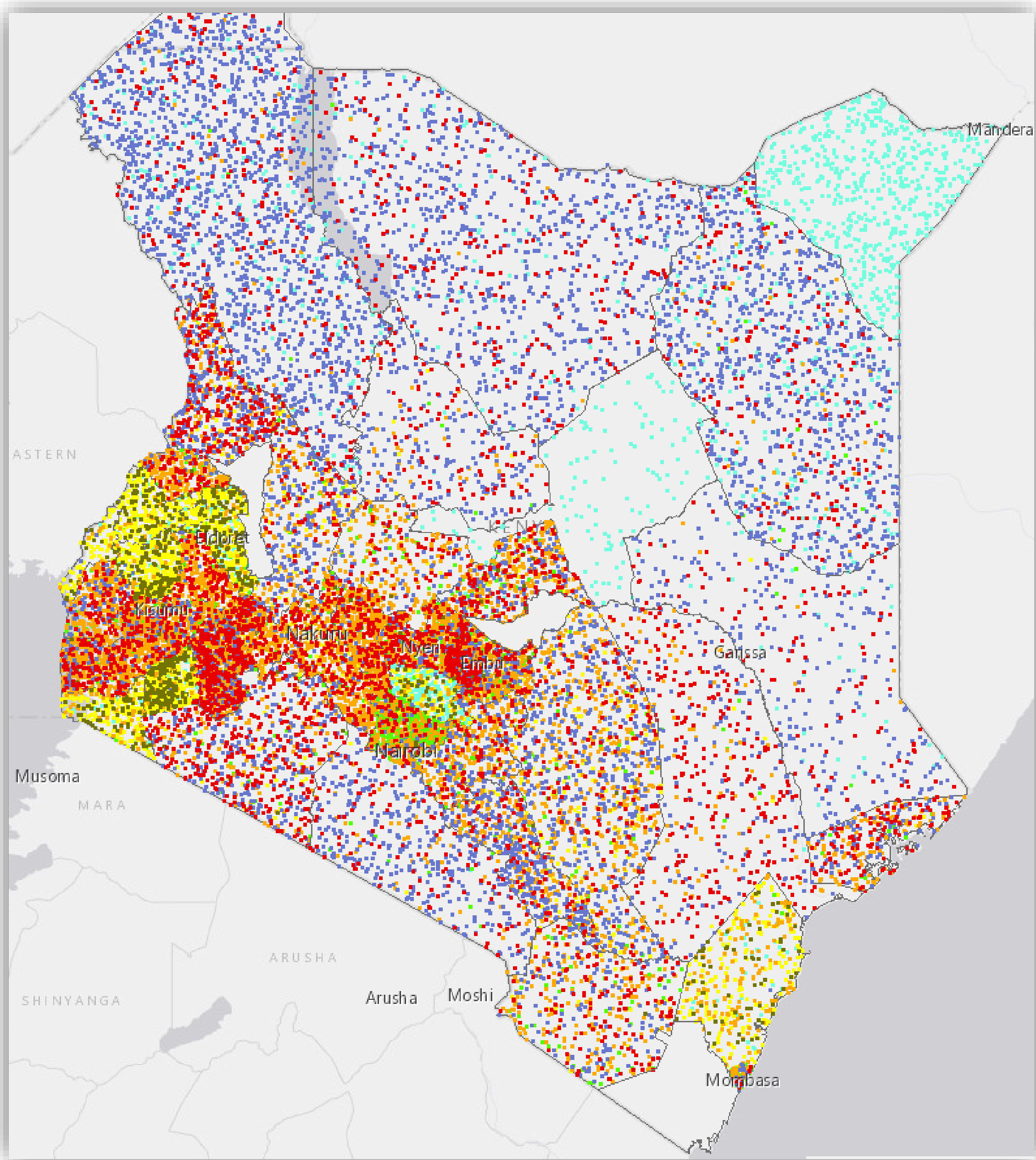


Figure 28 Screenshot from CFEP App: Data Gaps Due to Boundary Fluidity

areas where camels begin to outnumber other domesticated livestock—drier areas cannot support the domesticated stock but camels can thrive in arid areas.

The data exploration aspect of the CFEP allows users to overlay this layer with others and also to perform queries on the data. Section 4.4.1. listed the supporting data layers in the CFEP application. Section 4.4.2. discusses the VGI layers included in the app.

4.4.2. CFEP: VGI datasets

The original intent for the CFEP was for it to be used as a collaborative workspace for disparate aid groups and service providers to record patient demographic data, keep track of pesticide application and shoe distribution, and learn more about each other to stimulate cooperation and collaboration across distances. It is the collaboration that most interested the author: to provide a data repository for groups who don't even have a computer. Ultimately, it was understanding the potential real-world impact of the project that informed the decision to create the Tungiasis eLibrary. The CFEP goals are addressed through action at the local scale, but with changes to WHO NTD policy it could be possible to also combat tungiasis from the top down, through reclassification. The two apps together are meant to attack the problem of tungiasis from both political and practical ends, and in doing so ultimately fulfill the thesis project goals.

Interestingly, it is the CFEP that has garnered more attention from the tungiasis research community. It is precisely the VGI, the collaboration, that has attracted the curious and the serious. And with the rapidly-improving Collector App now available on both iOs and Android mobile devices, this dream could easily become a reality. At the time the development of the CFEP was initiated, Collector was not a viable option. Had the project been developed after the eLibrary, it is likely the author would have chosen the Collector App to populate the CFEP. The three VGI-soured feature classes of the CFEP are described in the following sections.

4.4.2.1. *Individual_Demographics*

The *Individual_Demographics* table is described in great length in the ERD section of Chapter 3. Several fields and domains were considered, built, re-considered, and re-built using ArcMap. The CFEP allows aid workers to use a form with drop-down menus to answer a series of questions about patients, to be recorded during medical visits by aid workers. As mentioned in earlier sections, the patient demographic data is intended to assist researchers in pinning down which societal risk factors are the best indicators of perpetual tungiasis. Table 11 lists the questions on the form. Once the feature class was created, ArcMap was used to publish a feature service using the REST service protocol. That REST service endpoint was consumed in the Chigoe Flea web map with the *Home_Visit* and *Service_Area* feature services to build the VGI portion of the app.

Table 11 Form Fields in *Individual_Demographics* Table

Gender	Has s/he had jiggers before?
Age	How long has s/he been afflicted (this time)?
Is s/he in school?	Can s/he walk comfortably?
School floor type	Does s/he have special needs?
Sleeping area floor type	Do animals have access to sleeping areas?
Does s/he provide care for other people?	Bedding Type
Is s/he given care by someone else?	Bedwetting
Married/in a committed relationship?	Does s/he share bedding with anyone else?
Waste Disposal	How far does s/he have to walk to get water?
Education	Livestock Type
Employed	Pets
Health	Rodents

4.4.2.2. *Home_Visit*

The *Home_Visit* table is similar to the *Individual_Demographics* table in terms of the data it contains but the data is being recorded about a homesite or sleeping shelter instead of a person. Pesticides are applied inside and outside shelters where tungiasis is persistent, so fields recording pesticide application and persistence were added to the database. Reminders based on the amount of time elapsed since application could alert aid workers to return to the area or be used for scheduling and routing purposes. Table 12 lists the questions on the *Home_Visit* form. Coded domain drop-downs for the questions asked were covered in detail in Chapter 3.

Table 12 Form Fields in *Home_Visit* Table

Floor Type	Interior Sprayed?
Livestock Indoors?	Exterior Sprayed?
Pets indoors?	Spray Persistence
Provided with shoes?	Presence of Rats?
Topical (medicine) given?	Waste Disposal
How far does s/he have to walk to get water?	

4.4.2.3. Service_Area

The third VGI feature class enables tungiasis-related service organizations or CBOs to draw the geographic boundaries of their effective service areas. Fields for a contact name, address, telephone, email, and website can be filled out to desired levels of completeness. The author populated this dataset with contact information available on websites found during research for this project, including Rise Up Society and Ahadi Kenya Trust, but drew in fictional service area boundaries. The website and app both state that these boundaries are fictional and used only to illustrate the feature class. After the website went live, Dr. Lynne Elson of the WAJMIDA Jigger Campaign contributed the service area of the organization with which she is affiliated. Figure 29 illustrates a feature from the *Service_Area* feature class volunteered by Dr. Lynne Elson.

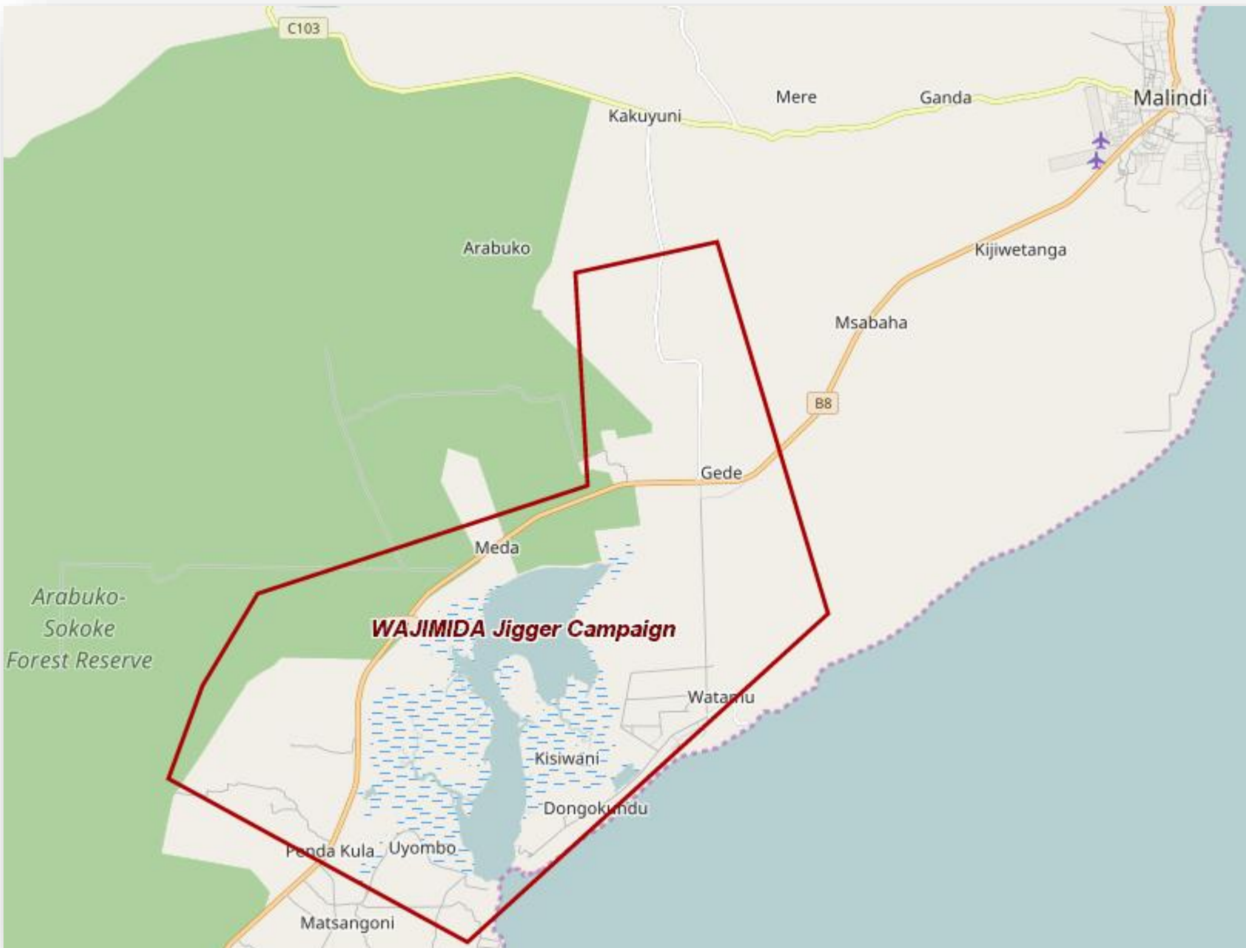


Figure 29 Screenshot from CFEP: Service Area of WAJIMIDA Jigger Campaign

4.5. Tungiasis eLibrary: Data Layers

The Tungiasis eLibrary, unlike the CFEP, does not require extensive supporting data layers. The focus of the application is to geolocate and categorize literature, not to explore GIS data, and the scale of the application is global, not national. This simplifies the update needs of the application and enables a more focused approach—the classification of tungiasis as a NTD. The following sections discuss supporting data and data derived from volunteering an article to the eLibrary.

4.5.1. eLibrary Supporting Data: the GADM International Boundary Dataset

International boundaries are surprisingly fluid in study area of this thesis; it is not uncommon for neighboring countries to dispute each other's claims to a particular region. For this reason, it was difficult to locate a GIS dataset that can be considered authoritative. Since this project intends to classify literature by country, an authoritative international boundary dataset was needed. To fulfill this need, the author utilized the database of Global Administrative Areas (GADM), which provides academics, other researchers, and web developers with an excellent, peer-reviewed open-source boundary dataset. This freely available spatial database of international and FLAU boundaries is maintained by the University of California, Berkeley, the International Rice Institute, and the University of California, Davis, and is intended for academic and non-commercial use. It is guaranteed accurate within one year. It has multiple granularities (administrative unit levels) to choose from, can be downloaded by country or globally, and is available in shapefile, Esri geodatabase, RData, and Google Earth kmz file formats.

The dataset not only includes boundary data; it also includes country names in multiple languages and alphabets. This will be handy for future work of expanding beyond English as the sole application language. In addition to multiple languages, attribute fields include: *WasPartOf* (i.e. the Soviet Union), *Contains* (i.e. Tibet is within China), *Sovereign*, *Pop2000* (2000 population), *SQKM* (territory area), *POPSQKM* (population density), *WBRegion*, *WBIncome*, and *WBDebt* (World Bank data). Additional fields, if *not null*, indicate membership in a particular classification, trade agreement, international body, or geography type. While not necessary for this application, future work might utilize this attribute data for analysis purposes. The CFEP and eLibrary both use data derived from the *NAME_ENGLISH* field.

The GADM can also be downloaded per country and displays multiple administrative level boundaries. The FLAU boundaries within Kenya are Counties. There are 47 polygon features within the dataset. Unlike the international dataset, the FLAU table only includes the boundaries and the name of the county, with no accompanying attribute data. This lack of attribute data both removes responsibility for its accuracy from the GADM and helps improve draw performance in web mapping applications since it is such a small table.

The FLAU boundaries layer is used in the Tungiasis eLibrary to produce proportional symbol maps indicating both the incidence of articles pertaining to a particular country, and will be used in future work to visualize VGI prevalence data (after it has been volunteered). The modified GADM was to be joined to the Tungiasis Bibliography table based on the *NAME_ENGLISH* field. However, during development the author elected to switch to point locations instead of polygons for several reasons: One, repeated problems arose when editing related tables in feature services (these bugs were resolved in ArcGIS for Server version 10.4, well after the project had been completed). Additionally, the choice between points (as schools) and multiple polygons (national, sub-national administrative units) added a level of complexity that on more than one occasion confused potential users, who desired a simpler data entry process. Additionally, administrative boundaries can and do change, especially in areas of political unrest—points remain stationary regardless of where the boundaries move to. Lastly, almost no articles contained data at the national scale while most pertained to specific locations, and the map produced by points represents a global spatial distribution of tungiasis—polygons would not have revealed these patterns. Since very little benefit was predicted from spending the time and effort to create three granularities of scale as originally planned, the author ultimately decided to use point features to represent articles rather than polygons.

Because there are more than 290,000 administrative areas mapped in the GADM, the dataset had to be altered to reduce complexity prior to inclusion in the application. Antarctica was deleted from the operating database to reduce load time. Since tungiasis is a disease of the tropics, countries in colder latitudes should be unnecessary for inclusion in the database, but testing did not reveal significant differences in draw time. One unique aspect of the eLibrary is the categorization of articles based on country of first author—there were in fact articles about tungiasis authored in Scandinavia! Thus, all countries in the GADM (with the exception of Antarctica) were subsequently included.

Even the international-level GADM dataset was sufficiently complex (and thus a large file) to warrant the cartographic generalization of features to improve performance. Generalization reduces line complexity by removing vertices from a polygon or line feature, improving load and draw times. Because the GADM dataset is used as a transparent layer over a satellite imagery basemap with labels, the visual complexity and or topology of the feature class is irrelevant. Even though slivers and dangles appeared after generalization, the scale at which this might impact application usage is smaller than the imagery that underlies it can zoom. Additionally, this boundary dataset is only used cartographically to create the choropleth maps that analyze statistics derived from an analysis of the collected articles. A layer depicting the number of articles about each country can be compared to a layer that shows the home country of first authors of articles; the two are surprisingly different (note the mention of Scandinavia above). Regarding the aforementioned topology inconsistencies, these choropleths were designed to only be visible at small cartographic scales for international comparison. These maps are shown in Chapter 5, Results.

Additionally, the GADM dataset was used to aggregate points for a proportional symbol map visualizing the number of articles related to each country, as seen here in Figure 30.

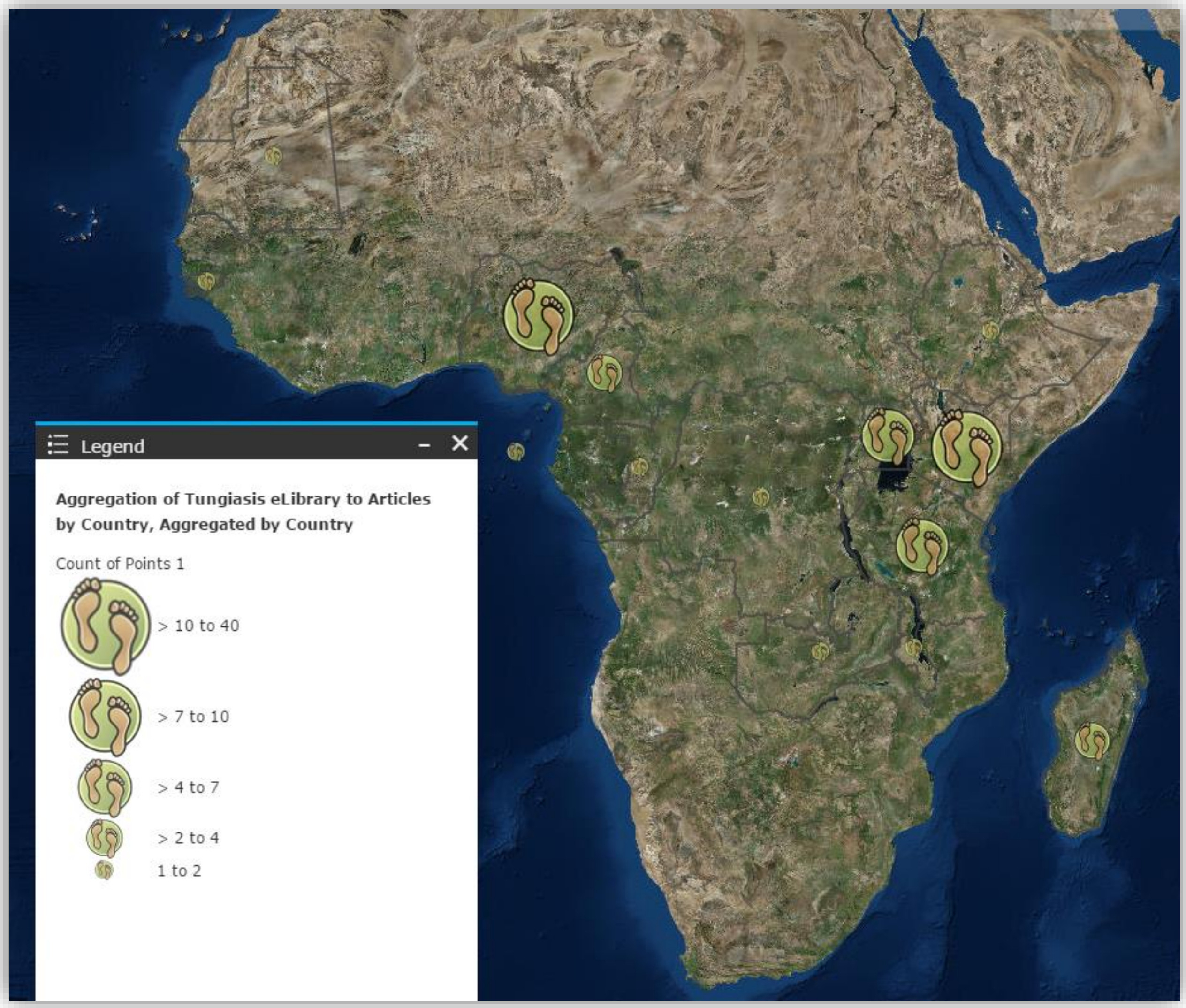


Figure 30 GADM used to aggregate articles by Country of Study

The “Country” domain is derived from the GADM Global Administrative Areas database. Specifically, the *adm0* shapefile was exported from ArcMap to Microsoft Excel using the Table to Excel tool in the Conversion Toolbox. The ISO (code) and Name_English fields were copied into a new workbook, and the code “0” with its “Global” description was added. The spreadsheet was then imported into ArcMap using the Excel to Table tool and added to the working geodatabase. Running the Table to Domain tool in the Data Management toolbox resulted in a 256-member domain of countries and the “Global” designation. Despite the large number of members in the domain, this supports data integrity and enables standardized geographic queries to be performed on the data. It prevents misspelling, and while not removing a language barrier it removes the burden of English spelling on users who may not call English their first language.

4.5.2. eLibrary Volunteered Data: Articles and Data

This project invites users to add entries to a tungiasis-related bibliography, where articles are georeferenced by country. This enables users to locate literature pertaining to a specific country using a graphical search on a web map. Any document, published or otherwise, can be volunteered. This dataset provides “evidence of the public health significance of the condition” required of WHO member states when requesting NTD classification for tungiasis (WHO STAG 2016). The collating of tungiasis-related literature is extremely valuable and addresses one of the main objectives of this thesis. This application could be interpreted as a workspace of sorts where pertinent literature is stashed. The thesis literature review and article selection (described in detail in Section 5.4.) have resulted in the inclusion of 132 peer-reviewed articles as of January 2017. Over half were entered using the Tungiais eLibrary web mapping application after its development. Articles are classified and typed upon entry. An editable web feature service was created using this dataset and published to a REST service endpoint for consumption in an AGOL WAB web mapping application. The app allows users to further contribute articles to the database. Since January 2017, at least three articles have been volunteered by tungiasis researchers. Table 13 lists the fields of the *Tungiasis_eLibrary* feature class.

Table 13 *Tungiasis_eLibrary* fields

Field Name	**Description**
Country_of_Study (Required)	List of countries derived from GADM and including "Global"
Article_Type (Required)	Journal Article (default), NGO Whitepaper, Government Paper, Prevalence Data, Gray Literature
Article_Focus (Required)	Populated when the literature's focus is selected: Survey or Study, Medical, Traveler, Information, Global and Public Health, Spatial Data, Veterinary, or Entomology/Biology
Focus_2	Same as above
1st_Author	Last name and first initial of article's first-listed author
Author_Country	Country where first-listed author resides, same list of countries as above
Year (Required)	Year of publication
Journal_Title	If Applicable
Article_Title (Required)	Article title, or some title by which literature or data can be referred to
Turabian_Citation	Complete Turabian citation. This field enables other users to search for all affiliated authors, not just the first listed.
DOI	Digital Object Identifier. This is a type of hyperlink used by academics and academic journals
URL	Highly recommended but not required if an attachment is added to the database
Attachments	If a PDF of the document is available and permitted to be shared, please upload it. Alternatively, if you have spatial data in the form of KML, shapefiles, or ZIP files, please upload those

The literature is classified in multiple ways in order to improve the search and browse experience and to standardize the data collection process. Articles are classified by country in the "Country of Study" field, which is restricted to a pre-set domain derived from the list of countries in the GADM. This restriction protects data integrity. The primary classification is literature “Type” that users can only select from a pre-set domain with the following values: Journal Article, Whitepaper (NGO), Government Paper, Prevalence Study, and Gray Literature. This is a required field. Each article also must be classified by its “Focus,” or topic, also restricted to the following domain values: Survey or Study, Medical, Traveler, Information, Global and Public Health, Spatial Data, Veterinary, and Entomology/Biology.

Classifying articles enables users to quickly locate an article by type: for example, “Traveler” cases are not of much use to veterinarians, and users interested in “Global and Public Health” may not care about the microbiology of tungiasis co-infections. These classes are also used to construct data layers for map visualization. Table 14 defines each classification and describes articles of each focus.

Table 14 Literature “Focus” Classification for Tungiasis Bibliography

Classification	**Article Description**
Entomology/Biology	Articles written by and for entomologists that focus on the biology and life cycle of *Tunga penetrans* or other Tunga species.
Veterinary	Articles that primarily focus on the impact of tungiasis on animals or livestock, or focus on animals as vector hosts.
Informational	Articles dedicated to furthering the overall Body of Knowledge about the insect Tunga penetrans, and tungiasis, or presenting general information and history.
Medical	Articles dealing primarily with microbiology (co-infections) and generalized medical treatment or medical complications of tungiasis.
Survey or Study	Articles documenting a study of tungiasis in a particular place at a particular time. The intent of these studies is to develop prevalences for tungiasis within a given area, or as a survey to determine underlying causes and risk factors. These studies are spatially explicit within the abstract or article full text.
Traveler	Articles written by medical professionals that encounter tungiasis in patients who have recently traveled to endemic areas. They are typically authored in non-endemic countries and so are georeferenced

	by location of infection. These do not provide prevalence data, but rather distribution data
Global and Public Health	Articles are written to further the cause of worldwide recognition of tungiasis as a public health concern. They cannot generally be georeferenced by study location because they address tungiasis abstractly. For this study, they are georeferenced as "World" and are placed in the middle of the Atlantic Ocean, at Longitude 45°00'00.0"W. Latitude varies with article type.

In the Contribute Data widget the article's focus is chosen from a palette of icons called a feature template. These icons are used to represent the feature class on the web map inside the application. They were customized to all be the same hue of blue and the same overall size to indicate their cohesion as a single dataset, but have different symbols for different foci. Figure 31 shows the WAB Contribute Data feature template icons for each article focus.

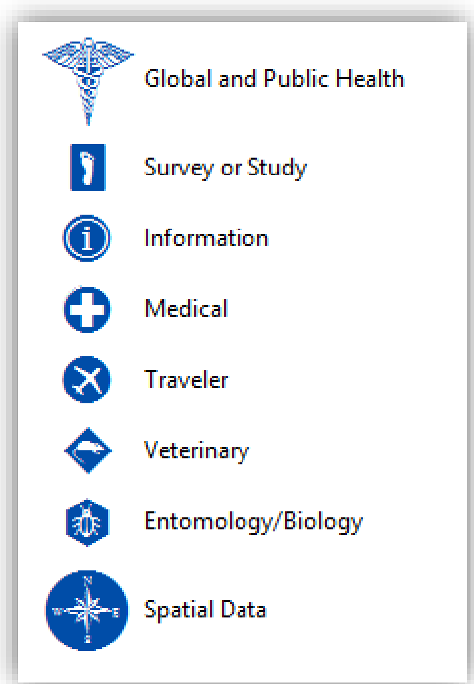


Figure 31 Symbols used for Article Focus types

Articles are further classified by entering data into other fields when volunteering the article. The "Secondary Focus" field allows a second selection from the Focus domain, to improve searchability and properly classify articles that might fit into more than one category. The "First Listed Author" field asks for the last name of the first author, also to enhance the search and browse experience. The app asks for "First Listed Author's Country" in order to analyze who and where articles are being published (more on this in Chapter 5). Also required at one time was a "Published Date" using January first of the published year in the format "1/1/2004." Time-enabled layers were generated but ultimately not included as the time slider did not add value to the data.

To better build a citation and improve the search experience, "Journal Title," "Article Title," and "Turabian Citation" fields are essential for academic research. The citation field can take time to fill out but enables other users to search for *all* affiliated authors, not just the first listed. The "DOI (Digital Object Identifier.)" field is optional; it is another type of link used by academics and academic journals. Perhaps the most critical field in the entire database is the "URL" field. If possible, users are asked to please provide a link to the article or data they are volunteering.

An "Attachments" field enables the upload of documents or data. If a PDF of the document is available and permitted to be shared, it should be uploaded. Users are invited to contribute prevalence data in the form of "Spatial Data" by the same process as adding an article. The feature server accepts attachments of many types (i.e. PDF, shapefile, zip file, geodatabase file, Microsoft Word document, spreadsheet).

Articles are placed as points on the map to best represent the study's location. In some articles, a first administrative unit name, village name, or region is mentioned. The point is placed either in the center of the smallest-listed administrative unit, or imagery is used to locate the point at an acceptable location. If more than one location is mentioned in an article, it is up to the volunteer to determine the most appropriate location. If an article is authored in a non-tropical part of the world about tungiasis as a traveler's disease, the location where infection occurred is used to georeference the article. If an article does not reference any geographic location but rather tungiasis itself, the "Global" value is selected from the "Country" dropdown list. To prevent these points from affecting the spatial distribution of tungiasis, users are directed to place the point marker with others of its same focus in the middle of the Atlantic Ocean, at Longitude 45°00'00.0"W. Latitude varies with article focus. Figure 32 shows the points representing articles with a "Global" georeferencing.

Chapter 4 discussed application development of the CFEP and eLibrary web mapping applications. The app development process from ArcMap to web app was laid out in great detail.

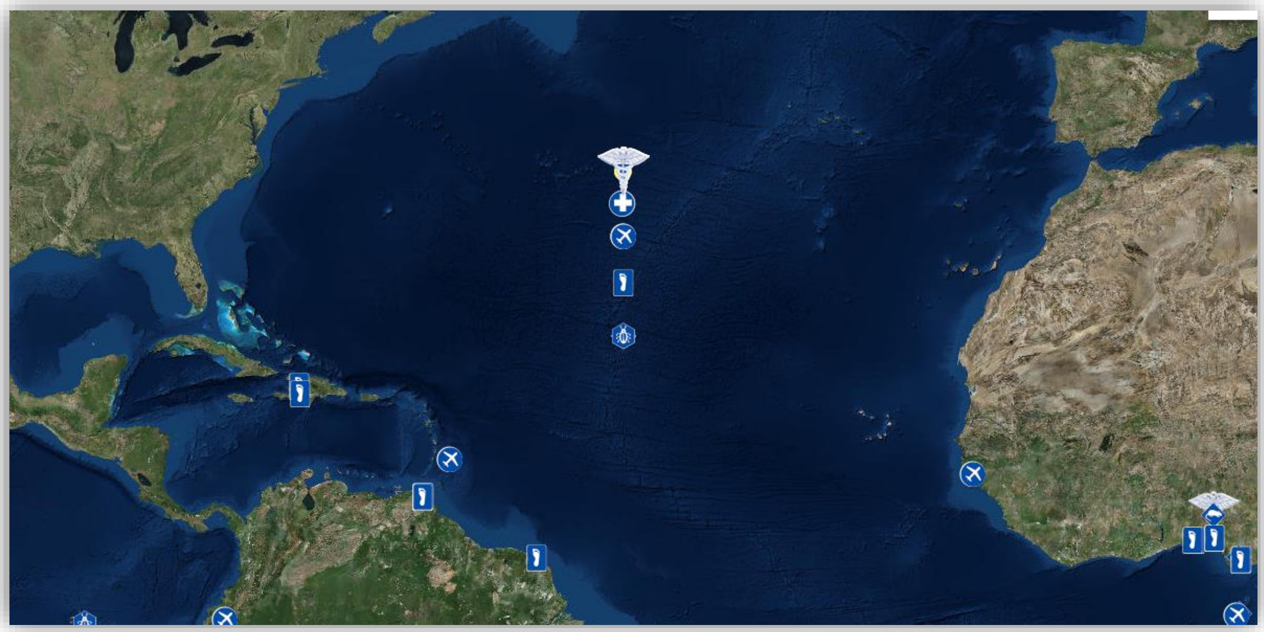


Figure 32 Articles with "Global" georeferencing

The different functionality between public and organizational AGOL accounts was sketched out, and a detailed description of the WAB app and each app's widgets followed. Data layers for both apps were described. Chapter 5 discusses application evaluation and testing, including feedback from public health and GIS professionals, and presents a meta-analysis of articles in the eLibrary collection.

Chapter 5 App Evaluation and Testing

This chapter presents a series of user workflows for each the CFEP and eLibrary apps and describes testing the applications. Contact with public health professionals in the tungiasis research field provided valuable feedback for each application, and In order to provide a seamless user experience, extensive help files were written for both apps. Section 5.1 discusses user scenarios for both apps. Section 5.2 lays out testing of the applications, and is followed by meta-analysis of the articles collected by the author and contributed by a health professional audience as of the date of this writing.

5.1. User Scenarios and Workflows

Section 5.1 lays out users and user scenarios for the CFEP and Tungiasis eLibrary applications. These workflows were tested using multiple browsers to ensure the same functionality for all users. Section 5.1.1. discusses potential user scenarios and workflows for the CFEP. Section 5.1.2. discusses user scenarios and workflows for the Tungiasis eLibrary.

5.1.1. CFEP User Scenarios and Workflows

From the local to the global, there is a demonstrated need for spatial mapping of tungiasis. The CFEP application was designed for use by three scales of users, identified in this section as “macro,” “meso,” and “micro,” corresponding to national, first-level administrative unit, and local scales. This section describes these potential users and user scenarios. All users are expected to have some knowledge of tungiasis but are not required to have any previous experience in GIS or using and sharing spatial data. A user that *contributes* data to the web GIS is identified as a “volunteer” for the purposes of this project, while a person who uses the app for *data discovery* is identified as a “researcher.”

Actors at the macro level might include the WHO or other inter-governmental organizations (IGOs), epidemiologists in national ministries of health, NGOs like the Bill and Melinda Gates Foundation, Doctors Without Borders, the International Red Cross, The Carter Center, or UNICEF. Actors at the meso-level might include public health officials at the FLAU such as a state, county, or province. In addition to the macro level, many NGOs or NPOs operate at a sub-national level, especially when the FLAU is large. In the United States, examples include state-level departments of health, while in Kenya these are county ministries of health. Epidemiological studies at the county level provide more detail than those at the national level. Distribution and prevalence data derived from these studies can provide other users with an idea of the severity of tungiasis prevalence within that FLAU, and will reveal areas where gaps exist in the data. Those areas can be further surveyed to determine what constitutes the gap. For example, some areas will not have available prevalence data, revealing a gap on the map. Similarly, confirmed records of "no pest present" will also create gaps on the map. Gaps of the first type indicate a need for further investigation, while gaps of the second type indicate either eradication success or lack of endemicity.

Actors at the micro level might include CBOs providing humanitarian aid to villages or regions, academics studying tungiasis in specific communities, local health officials, or doctors. While not meaningful (without context) at the international scale, statistics at this granularity provide the most detailed picture of tungiasis distribution within a region. Users at this scale are both *researchers* and *volunteers*, donating the data as it is collected at the micro scale. It is also feasible to collect small-scale prevalence data, as an entire community can be surveyed at once. As part of an IC program, a CBO or NGO could distribute bed nets, prenatal vitamins, antiparasitics and antimalarial medicines while also surveying the community for tungiasis prevalence data. As noted in Chapter 2, locals may have a much better concept of community epidemiology than "specialists" at the national scale (Hunt 2006). This facilitates the movement of data from the micro to the macro scale, removing the red tape as a barrier to information-sharing and opening a line of communication between all user tiers.

Three feature datasets capturing VGI were created to allow users to enter data into the web mapping application. The Contribute Data widget enables users to input data into a database in order to better address the challenges of managing a widespread EPSD. Users are welcomed to enter humanitarian aid organization coverage areas, individual demographics, and structures treated with pesticides. Organizations (charities, NGOs, etc.) that operate in eastern Africa providing medical care, humanitarian aid, and education about tungiasis prevention are invited to enter contact information and draw an approximate coverage area on the map. Health and humanitarian aid workers and volunteers are invited to enter demographic information about Tungiasis-afflicted individuals. Patient privacy is of vital importance, and no identifying factors are recorded. As aid workers visit homes and apply pesticides, they are invited to record attributes of each site visited and treated.

The Query Attribute widget can be used to display records that match a specific value or set of values. For example, users can explore areas where less than 50mm of rain falls per year, find out where camels outnumber donkeys or explore schools that lack a toilet by viewing pre-set queries. The Analysis widget has been renamed Analyze, Buffer, and Overlay to better reflect the spatial analysis tools that are enabled (its icon is a circle with dots in it). The Analysis widget is a special tool that performs various spatial analysis or geoprocessing functions. These functions are essential to exploring spatial relationships between layers. The Analysis widget only works when the user is logged into the AGOL organizational account used to publish the application. To use the widget consumes Esri credits (which do equate to real-world dollars); as previously stated, the standard rate as of May 2017 is 1 credit per 1,000 features analyzed. (The number of credits per USD is dependent upon the service level agreement with Esri, so published prices are hard to find.) These credits are charged to the organizational account hosting the web app; in this case, USC SSI. Sample Layers of these tool outputs are included in the layer list. The Measure widget allows users to take an approximate measurement of a line between objects, or area of a polygon. The ability to Select Area, Distance, or Location is also included. The default measure is in kilometers. To explore all Attribute Tables, users can click on the arrow in the middle of the bottom border of the map. Attribute Tables are navigated as tabs and can be filtered by extent or content.

5.1.2. Tungiasis eLibrary User Scenarios and Workflows

Because the theoretical goal of the Tungiasis eLibrary is to assign NTD status to the disease, the author assumes that most users will have some familiarity with tungiasis and NTDs in general. Thus, the two most important workflows for the eLibrary which satisfy the thesis objectives include volunteering data using the “Contribute Data” widget and using the Search for Articles widget to browse the bibliography.

While CFEP users were best defined by scale, the Tungiasis eLibrary is better examined by user profession. Because there is no restriction to article topic, it is possible to capture an audience consisting of medical doctors, epidemiologists, geographers, public health officials, global health professionals, academics, and other users all contributing to and browsing the eLibrary. This inclusion of all topics also works to forward the project objectives of developing a body of evidence proving the need to upgrade tungiasis to NTD status, and bringing awareness to the disease.

Other users might include the simply curious. Much of the collected literature pertains to travelers' diseases—typically parasitic diseases contracted in tropical regions and "brought home" by patients who are unaware they host foreign parasites. Of the 132 collected articles at the time of publication, 24 of them were classified as "traveler" related documents. These articles were written by doctors—almost exclusively dermatologists—who unexpectedly encountered *Tunga penetrans* in non-endemic countries. Academics might also find value in a georeferenced library pertaining to one particular subject, particularly if leading specialists in that particular field are encouraged to "volunteer" their own work to the collection, published or no.

5.1.2.1. Volunteering Data Using The "Contribute Data" Widget

The Contribute Data widget enables users to input—or "volunteer"— journal articles, whitepapers, gray literature, and government papers that pertain to Tungiasis to the eLibrary database. The workflow to contribute data is illustrated in Figure 33.

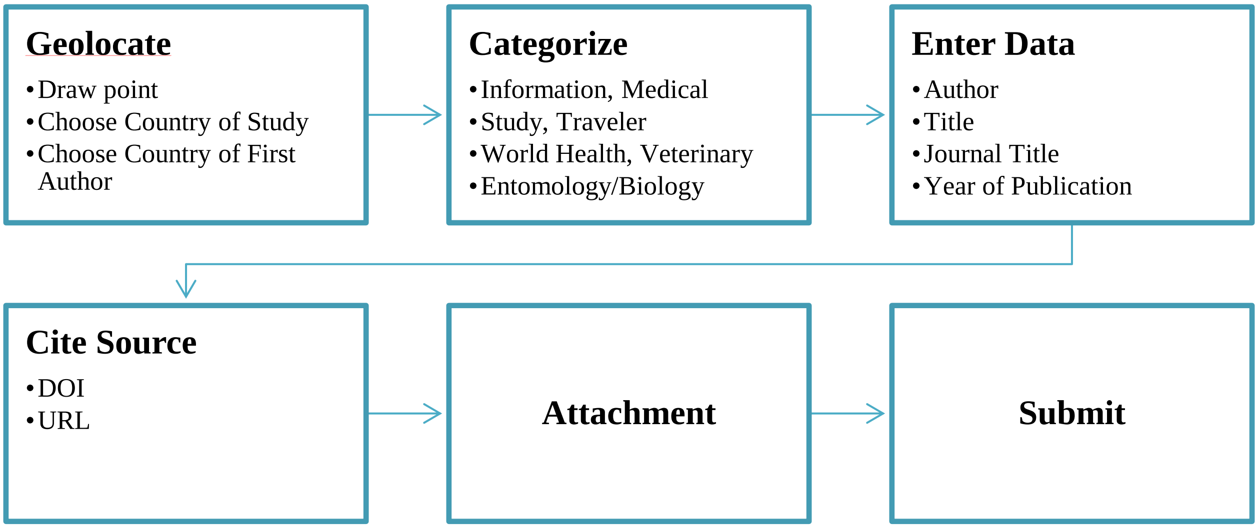


Figure 33 VGI workflow for Tungiasis Bibliography

In order to volunteer the data, the user should first determine the literature's main "Focus." After choosing a focus, users are presented with a palette of icons from which to choose: Survey or Study (labeled Tungiasis eLibrary in the image), Medical, Traveler, Information, Global and Public Health, Spatial Data, Veterinary, or Entomology/Biology. Figure 34 shows the Contribute Data widget.

The user then determines the article's geographic focus. Most articles contain detailed location information, but not usually exact coordinates. The user should locate a point on the map roughly equivalent to the location of the study. For articles with a Global focus, the point should be placed with others of its same focus in the middle of the Atlantic Ocean, at Longitude 45°00'00.0"W. Latitude varies with article focus (see Figure 32 for an image of this configuration in Section 4.5.2). When the point has been placed, the panel will change into a form requesting certain data attributes.

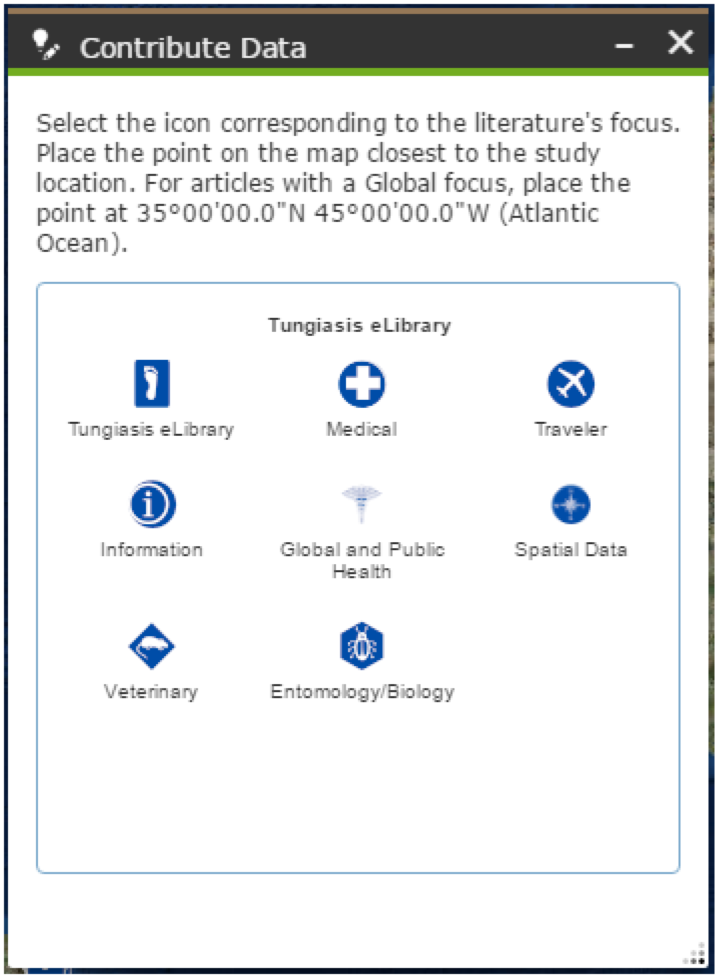


Figure 34 The Contribute Data Widget

5.1.2.2. Querying the database using the "Browse Articles" Widget

The Browse Articles widget provides users with pre-set queries that add meaning to the collected data. The Search by First Author tool allows users to select an author's name from a drop-down list populated with existing records from the "First Author" field of the feature class. Thus, this tool will only return articles that have a populated "First Author" field. More similar to a library search, users can type in an author's last name to the Search All Authors tool to search all authors affiliated with an article, provided its Turabian citation is entered into the database.

This performs a full-text search on the “Citation” field and returns any article with matches. This is the most comprehensive way to search the database by author, journal title, or article title. The Search by Country of Study tool allows users to select the country of study from a list. The list is populated by the “Country of Study” required field rather than the domain derived from the GADM, so users can only select from countries that have already had articles georeferenced. Similarly, the Search by Country of First Author tool allows users to select the first author’s affiliated country from a list. For example, select “Brazil” to see all articles authored by a Brazilian. This query only returns records that have a populated “First Author Country” field. The Search by Journal query allows users to select a Journal’s name from a list. It will only return records that have an affiliated Journal Title.

The Search by Type of Literature tool allows users to filter articles based on their “Type” (Journal Article, NGO Whitepaper, Government Paper, Prevalence Data, Gray Literature). The Study Country/Author Country Different query returns all articles whose first author lives in a different country than the study pertains to, except for articles of with “Global” emphasis. Users can also search by article “Focus” using domain-specific queries. The Epidemiological Literature query returns all articles whose Primary or Secondary Focus is “Survey or Study.” The Traveler Literature query returns all articles whose Primary or Secondary Focus is “Traveler.” The Entomological/Biological Literature query returns all articles whose Primary or Secondary Focus is “Entomology/Biology.” The Veterinary Literature query returns all articles whose Primary or Secondary Focus is “Veterinary.”

It is the presence of peer-reviewed scientific literature that legitimizes this application. Users are invited to submit to the eLibrary to increase the body of knowledge collected about tungiasis. As previously mentioned, this collation of documents can then serve as a “dossier” of evidence of the public health concern caused by tungiasis when WHO member states petition to have tungiasis reclassified as an NTD.

5.2. Testing the Applications

Both applications were tested by the author for consistent functionality, and workflows were documented in the Help files of each app. This section briefly discusses testing the apps after initial development.

5.2.1. Testing the CFEP

The CFEP includes a Help widget that opens automatically on load, but because the Help widget is located in the header controller, it cannot be resized. The CFEP Help widget is shown in Figure 26 in Chapter 4. While not color-coded like the eLibrary Help file, it is detailed and explains how to use each tool. Testing of the CFEP involved imagining various user workflows based on user scale as discussed in Section 5.1.1. Actors at the local level would open the app in a browser on either a connected mobile device or computer, and record data as questions are answered. In this vein, the author tested the functionality of all drop-downs in the *Individual_Demographics* and *Home_Visit* VGI feature classes within the Contribute Data widget. All widgets, including supporting widgets, were tested to make sure they were working within multiple browsers (Chrome, Edge, Internet Explorer, Opera, Safari, and Firefox/Mozilla). If a problem was identified during testing, the corresponding behavior was altered in the web map or app.

Actors at the meso-level might choose to overlay supporting data layers to determine areas where greater attention is needed. To test this, the author performed spatial analysis using the Analyze, Buffer, and Overlay widgets, checking the outputs of each of these operations made possible by credits in the USC SSI AGOL org account. Acting as a meso-level user, the author tested the *Service_Area* feature class in the Contribute Data widget. In addition, Dr. Lynne Elson used the widget to enter the service area of WAJIMIDA Jigger Campaign, pictured in Section 4.4.2.3. Because actors at the global level are imagined to be researchers, the Query Attributes widget was tested to return all pre-built queries, viewing all outputs for correctness.

5.2.2. Testing the Tungiasis eLibrary

Testing the Tungiasis eLibrary was a matter of populating the feature class with the collected articles, and then requesting users test the app and provide feedback. After creating the initial feature class with approximately fifteen entries using ArcMap and entering data directly into the attribute table, the author populated the remaining records using the app interface. This tested the user experience and informed changes to the app as needed. In fact, it was during testing that WAB BUG-000086319 (GeoNet 2016) was encountered and reported to Esri's WAB developer team at the 2017 DevSummit in Palm Springs, California (www.esri.com/events/devsummit). Developers had previously reported that the bug had been resolved, but demonstrating the BUG in person proved that it had not. The issue involves the automatic insertion of commas into numeric values in the Query widget in WAB. Even if the map service and the web map had disabled the separation of numbers with commas, they still appeared Additionally, at the 2017 DevSummit, developers participating in the summit were able to provide assistance with a randomized text string that appeared as the default value for "Year," so even though the field type only allowed numeric data at a maximum of four digits, the value that popped into the field in WAB showed this random text string by default. It turned out the author had introduced this text in the feature template accidentally a few months earlier when trying to give the "Survey or Study" icon its correct label. While the feature template was open a series of characters were unknowingly entered, and it was recorded into the service when it was next re-published.

Feedback from individuals working to combat tungiasis in Kenya was critical to understanding what needs to change before the app is deployed in the field. As articles were being collected for inclusion into the eLibrary, email addresses of affiliated authors and journal editors were recorded in a spreadsheet for future contact. From November 2016 to February 2017, the author contacted over fifty authors of tungiasis-related articles via email, introducing the project and requesting they visit the website and test the application. Links to the websites were provided, along with the author's contact information and links to the Esri ArcUser magazine article and USC newspaper article profiling the project (Stevens 2016, Bell 2016). A few article authors replied with general messages of encouragement and feedback.

Public health professionals at Emory University's Task Force on NTDs were contacted, as were other prominent NTD researchers. Rebecca Mann Flueckiger responded with feedback about the application that was not feasible to implement since her suggestions all involved the use of a team of epidemiologists and GIS professionals, while this project is a singular effort. The author reached out to government officials in Kenya's MOH but received less-than-enthusiastic responses; each person directed the author to contact another person or government bureau but failed to include contact information for each suggested contact. Lastly, the author requested that co-workers and fellow students visit the project websites to test the user workflows and provide feedback.

In January 2017 information about this project was posted on LinkedIn. In that same month, the author met with two tungiasis researchers from the University of Nairobi in Kenya via Bluejeans web conferencing service, facilitated by Dr. Jennifer Swift of USC SSI. Dr. Peter

Keiyoro and his associate Dr. Josephine Ngunjiri, who had learned of the project from Dr. Jörg Heukelbach of the Universidade Federal do Ceará, in Fortaleza, Brazil, provided essential feedback about both applications. Dr. Keiyoro in particular spent considerable time with the author learning how to use the eLibrary and uploaded several unpublished and published articles he and his associate had authored.

Drs. Keiyoro and Ngunjiri expressed surprise that the attached articles were supposed to be generated by VGI and not a static collection curated and maintained by the author. Additionally, one of the anonymous responses in the survey shared this misunderstanding of the app, stating the eLibrary was not an authoritative collection of articles. This made apparent that the basic principle of the eLibrary—VGI—was not clear to the eLibrary app users, and necessitated a change in future versions to ensure better user understanding. At Dr. Swift's suggestion during the web conference with Drs. Keiyoro and Ngunjiri, the author did a live demonstration showing how to use of the eLibrary, how users upload their own work and link to published articles using the Contribute Data widget in the app. The demonstration led to immediate understanding and excitement from the two as they realized they could independently upload their own research to the centralized database. Since the demonstration had been so effective in communicating the workflow the author created a Jing (screencast) video recording to demonstrate the Browse Articles widget (https://www.screencast.com/t/OYnyZ1nwbddo). A Jing video demonstration on how to contribute files was also added to the website to assist future users (https://www.screencast.com/t/9zzscLzD).

5.2.3. Help Files and Sample Data

Detailed use instructions were included on the "How To" tab on the project web pages and in the "Help" file widget in each WAB application. Like the NTD Mapping Tool Quick Help

Document shown in Figure 5 in Section 2.1.1.1, the eLibrary has an annotated screenshot to guide users, shown in Figure 35.

Figure 35 Tungiasis eLibrary Quick Help Document

The Help widget window automatically opens when the app loads, a behavior that can be modified using the WAB developer interface. Sample data is provided to users to test the Contribute data widget, shown in Table 15. The eLibrary "How-To" tab, shown in Figure 36, includes more detailed instructions.

Table 15 Sample data for entry into the Tungiasis eLibrary

Mwangi, Jamleck N., Hastings S. Ozwara, and Michael M. Gicheru. 2015. "Epidemiology of *Tunga penetrans* infestation in selected areas in Kiharu constituency, Murang'a County, Kenya." Tropical Diseases, Travel Medicine and Vaccines 1, no. 13.
URL: https://tdtmvjournal.biomedcentral.com/articles/10.1186/s40794-015-0015-4

Help

Welcome to the Tungiasis eLibrary, a user-generated bibliography of tungiasis-related research.

For detailed instructions and helpful videos, please click the "How To" tab on the website.

Basic Map Controls:

- **Zoom** in and out to see more layers, using the **+/-** button or the mouse scroll wheel.
- **Home** zooms the map out to its full extent.
- **Search** bar at the top of the map can be used to search for places using keywords or coordinates, powered by Esri.
- **eLibrary Search** enables users to search the library using the entire citation. Best overall search of the eLibrary.
- **Basemap Gallery** (four-pane square) allows users to choose different basemap styles.
- The **Help** feature contains instructions on how to use the app, also found here.
- To explore all **Attribute Tables**, click on the icon that looks like a table.

The **Launch Pad** at the bottom of the map contains **Widgets**, or in-app functions, represented as round icons. From Left to Right:

- The **Legend** shows layers visible at the current scale--as you zoom in on the map, different layers will appear.
- The **Layer List** displays all data associated with the web application, including layers that are currently turned off.
- The **Browse Articles** widget provides users with pre-set queries that add meaning to the collected data
- The **Contribute Data** widget enables users to input, or "volunteer," data.
  - Determine the main **focus** of the literature:
  - Determine the **location** of the article. Locate a point on the map roughly equivalent to the location of the study.
    - For articles with a Global focus, please place the article with others of its same focus in the middle of the Atlantic Ocean, at Longitude 45°00'00.0"W. Latitude varies with article focus.
  - Place the point. The panel will change into a **form** requesting multiple data attributes.
- The **Chart** widget allows users to see various attributes displayed in a pie or bar chart.
- The **Select and Export** widget offers users the ability to select data and export it in various file formats.
- The **Bookmark** widget contains a list of bookmarks providing users with locations of interest on the map, and enables users to create their own bookmarks.
- To see the **Time** animation, turn off the Tungiasis eLibrary layer in the Layer List, and then click the time button. The widget plots the points in the order of the year they were published in an interactive animation.

Feedback and suggestions for new data are welcome! **Please take the User Survey through the website or by clicking** HERE.

Figure 36 Tungiasis eLibrary Help Widget

Ultimately, while Drs. Keiyoro and Ngunjiri were impressed with the Tungiasis eLibrary, they and Dr. Lynne Elson of WADJIMA Jigger Campaign in coastal Kenya were more interested in the CFEP and the possibility of mapping tungiasis prevalence at the local level using mobile devices. In fact, this interest in the CFEP led to an invitation from Dr. Feldmeier to co-author a journal article with he and Dr. Elson about grassroots and global efforts to fight tungiasis, to be included in a future special issue of the Journal of Tropical Medicine and Infectious Disease.

5.3. Meta-Analysis of Collected Articles

Once the problem and research objectives were defined, as previously stated in Chapter 2, the author performed in-depth research of *T. penetrans*, tungiasis, global public health initiatives, medical GIS, epidemiology, web cartography, VGI, and application and website design principles in preparation for the project. As part of this thesis document, a meta-analysis of articles is included to reveal patterns in publication about the disease. A meta-analysis can be useful to determine “which countries are the most influential in a chosen field, who are the important opinion formers within academic discussions, and where current research trends within a given field lie” (Arden 2008; Tutarel 2002). The full meta-analysis is presented in this section.

In order to systemically select literature for inclusion, the GNTD article selection framework and inclusion criteria shown in Figure 8 were combined with Tutarel’s and Arden’s meta-analysis methodologies discussed in Section 5.3.1 (Hürlimann et al. 2011; Tutarel 2002; Arden 2008). Using the Google search engine, Google Scholar, USC Libraries, PubMed, and PLoS, the author located one hundred thirty-two articles to be included in the Tungiasis eLibrary. Search terms included “tungiasis,” “*Tunga penetrans*,” “jigger,” “chigoe flea,” and “sand flea.” PubMed, a service of the United States National Library of Medicine (NLM), provides free online access to the NLM's MEDLINE, a database of indexed citations and abstracts from medical, nursing, dental, veterinary, health care, and preclinical sciences, and contains references and links to articles in other databases (PubMed 2016). PLOS, or Public Library of Science, is an NPO founded in 2003 dedicated to publishing scientific literature under the Creative Commons "attribution" license and advocating unrestricted access to medical knowledge worldwide (PLOS 2016). This open-access database proved highly fruitful, resulting in a number of articles pertaining to tungiasis, NTDs, and IC that were used to write Chapter 1. In fact, one article discussing new mapping technology as applied to epidemiology actually meta-referenced its own journal *PLOS Neglected Tropical Diseases* as an example "of the power of the new technologies, since the open-access format permits the data, analyses, and predictions to be published in a way that maximizes access to the information" (Brooker, Hotez, and Bundy 2010). Similarly, the bibliography of tungiasis articles at the Global Infectious Diseases and Epidemiology Network (GIDEON) was heavily relied upon (GIDEON 2016), but a good portion of those articles were published prior to 1990. Preference was given to literature published since 2005, so in the interest of time, publications written prior to 2000 were rejected (with a few exceptions made based on article relevance or meta-reference by other articles). While the GNTD selection process rejected over 70% of initially-selected articles (Flueckiger et al. 2015), this level of exclusivity was not necessary for a project of this scope; while the GNTD group was collecting vetted prevalence data, the Tungiasis eLibrary focuses on *all* literature that pertains to tungiasis, including sociological articles and programmatic implementations in endemic areas for inclusion in the Tungiasis eLibrary. The search returned several articles pertaining to neglected tropical diseases in general, but these were not included as tungiasis was not the main focus. Some search results were "gray literature," that is, conference proceedings, meeting minutes, health ministry publications, and unpublished theses and dissertations. Seeing such a wealth of unpublished work informed the inclusion of these types of articles in the eLibrary. The references and bibliographies of these and other documents from the CDC, WHO, and the Task Force for Global Health were mined to locate other tungiasis-related data. In part, the Tungiasis eLibrary, in the form of a bibliographic web map, was a direct result of searching multiple repositories for literature referencing tungiasis and getting spotty or duplicate returns. All told, over two hundred tungiasis-related articles were reviewed for inclusion in this project, many of which are represented in the References. Figure 37 represents the article selection methodology used to collect and determine fitness for inclusion into the Tungiasis eLibrary.

The collected/volunteered articles all have at least one thing in common: all are, in some way, focused on tungiasis or *T. penetrans.* Apart from that single common factor, many of these articles might never be grouped together. While the Tungiasis eLibrary does not claim to be absolute and complete, it is to date the only online repository composed of tungiasis-related literature. Tutarel's journal article describing the geographic distribution of publications in the field of medical education used impact factor (IF)—a measure of the frequency of citations within a particular year—to rank the 13 journals included in the study and narrow the journal search field to two. Because this project has such a narrow focus (tungiasis) relative to Tutarel's (medical education) and due to the deliberate inclusion of unpublished work in the eLibrary, IF was not considered in any way when collecting articles to populate the dataset and no restrictions were placed on source. Tutarel's search methodology used PubMed to search Medline for journal articles published between 1995 and 2000 that were returned from the *Academic Medicine* or *Medical Education* journals.

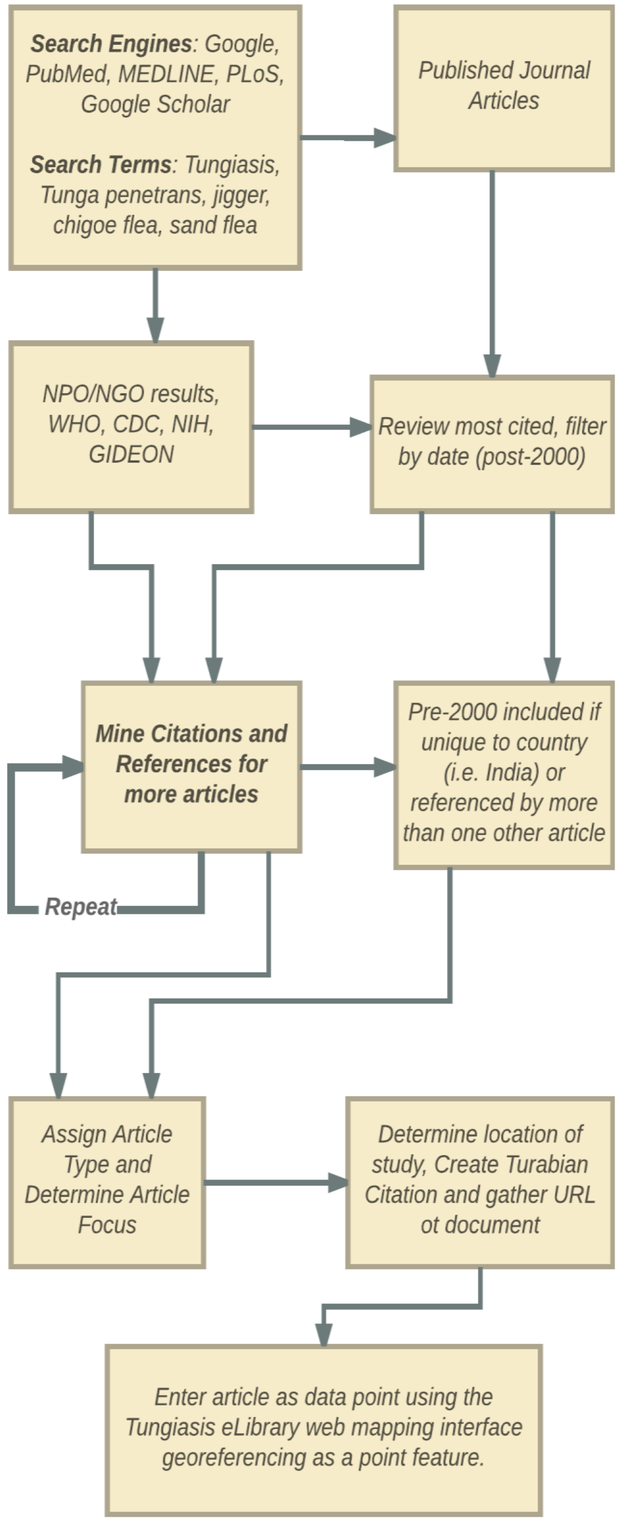


Figure 37 Article Selection Methodology for the Tungiasis eLibrary

Those results were georeferenced using the articles' affiliations (university within a country) and if more than one country was listed, each of them was rewarded with a count (Tutarel 2002). Arden's 2008 dissertation modified that methodology by applying the meta-analysis to tropical disease research and GIS-specific case studies in Brazil. This thesis study borrows from each methodology, further focusing the search terms to apply to tungiasis research with the objectives of determining the geographic distribution of study locations, examining which articles' first authors are affiliated with afflicted countries versus developed countries, and analyzing article by type and focus.

5.3.1. Meta-Analysis Results

The Tungiasis eLibrary main feature class was exported from ArcMap to Excel using the Table to Excel tool in ArcToolbox. The resulting table was analyzed using the COUNTIF Excel formula for each of the following attributes: Country of Study, Article Source, Primary Focus, Secondary Focus, First Author, Country of Author, Journal Title, and Year (of publication). The results were recorded in an Excel Spreadsheet and used to produce this meta-analysis.

5.3.1.1. Geography: country of study and country of first author

As articles are volunteered to the eLibrary, three types of spatial data are collected: the latitude/longitude point data generated by placing a point on the map, the Country of Study drop-down list (which is a required field) and the Country of First Author drop-down list. The point data serves to create the spatial distribution of tungiasis revealed on the mapping application, while the Country drop-downs are used for this meta-analysis.

Twenty-five different countries are represented in the Tungiasis eLibrary, with a Global category representing articles with a worldwide scope. By far, Brazil has the highest number of associated studies at 42 articles. A distant second is Kenya with fifteen, and after that Nigeria (9), Tanzania (7) and Argentina and Uganda (6). Figure 38 provides is a map showing countries with the number of Tungiasis eLibrary articles applicable to each country.

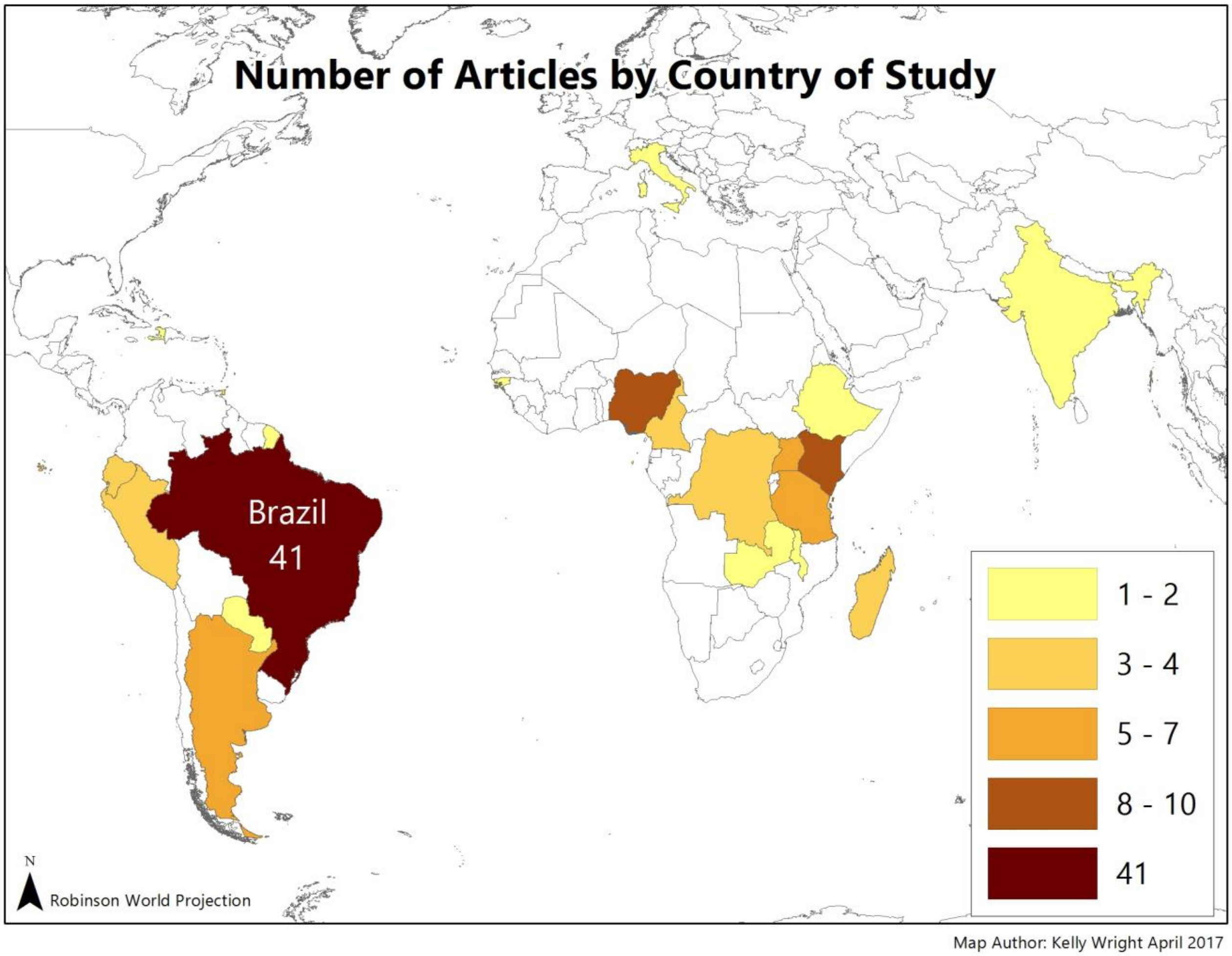


Figure 38 Mapping the Number of Articles by Country of Study

5.3.2. Authorship and Location of First Author

92 individuals were listed as first author on the 132 articles collected. The two most prolific first authors were Jörg Heukelbach and Hermann Feldmeier with 14 and 11 articles, respectively. While Dr. Heukelbach lives and works in Brazil, where he is a leading tungiasis

scholar, Dr. Feldmeier lives in Germany which has no incidence of tungiasis. Heukelbach is affiliated with 48 of the collected articles, and Feldmeier is affiliated with 38. Within the NTD community and other disciplines it is the prestige of the main author that provides academic legitimacy that the study's actual authors might not yet command. It is interesting to postulate that despite the intimate local knowledge that most later-listed authors have about tungiasis in their region, it appears that only because they are publishing with these respected researchers that they are granted publication. And, when considering the ethnicities of these tropical countries, it is often authors of color that are being listed second author or later due to the prestige of Feldmeier's and Heukelbach's names. Figure 39 shows the countries of first authors in the Tungiasis eLibrary.

5.3.2.1. Article Type

There are five "Types" of data in the Tungiasis eLibrary: Journal Article, Whitepaper, Gray Literature, Government Paper, or Spatial Data. At this time, no spatial data has been uploaded to the database. A future goal of this study is that the CFEP be used to populate the Tungiasis eLibrary with spatial data. Of the 132 collected articles, an overwhelming 127 are Journal Articles. There are 3 Gray Literature (unpublished work) articles that were volunteered to the database after it deployed. There is one whitepaper from the WHO and one Government paper from the Kenya Ministry of Health. The reason for the high number of Journal Articles is the purpose of the database to serve as a dossier of public health information about tungiasis.

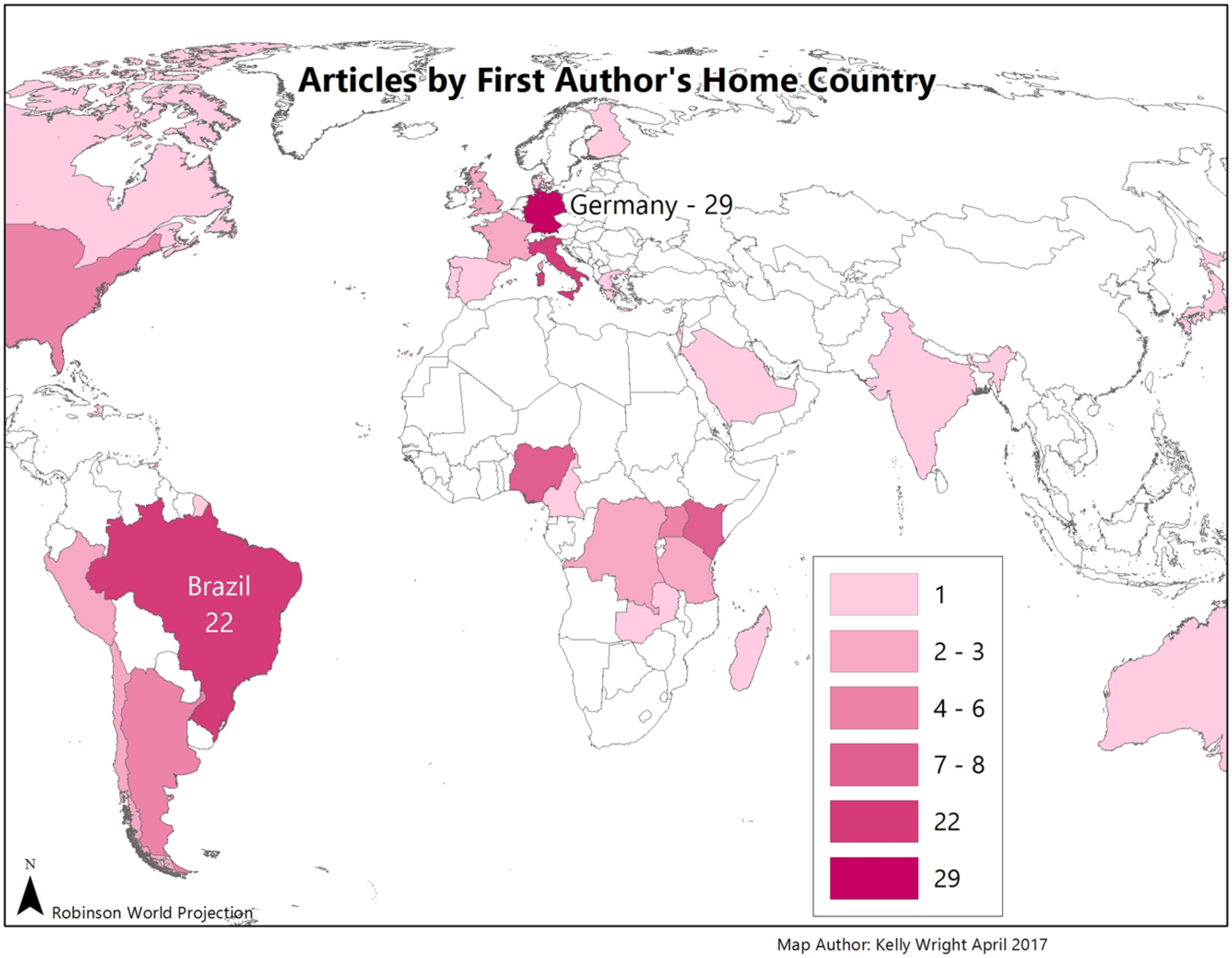


Figure 39 Mapping Articles by Country of First Author

5.3.2.2. Article focus

There are seven categories of article “Focus” in the Tungiasis eLibrary: Survey or Study, Traveler, Global and Public Health, Veterinary, Entomology/Biology, Medical, and Information. Eighty-one articles were tagged with “Survey or Study” as a primary or secondary focus. At a distant second is “Medical” with 43 articles, followed by “Traveler” with 24. A total of 22 Articles were tagged with “Global and Public Health” and 20 with “Veterinary.” There were 19 articles classified as “Entomology/Biology” and 13 marked as “Information.” Since articles could be tagged with both primary and secondary foci, these numbers add up to more than the 132 collected articles. Figure 40 shows a histogram of the number of times each “Focus” was used to describe either the primary or secondary focus of an article.

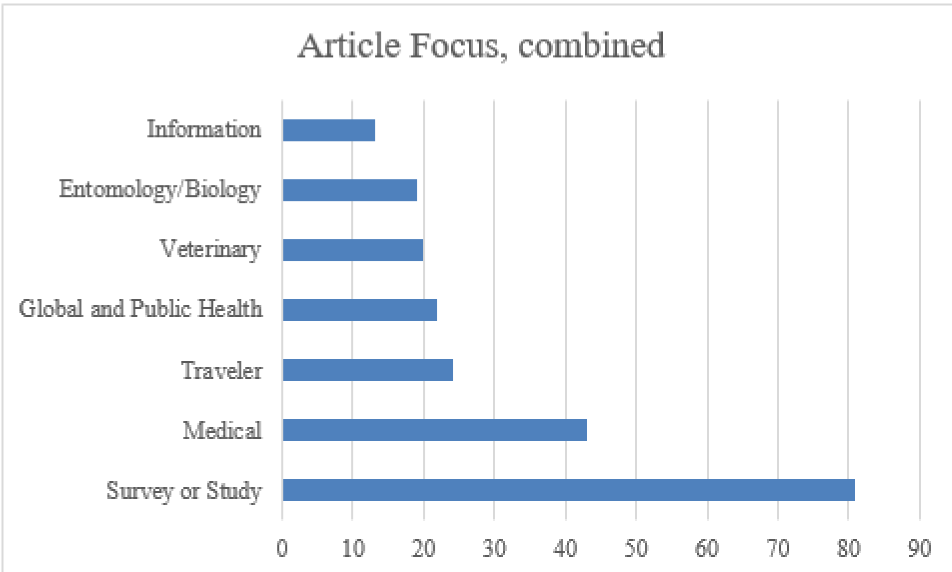


Figure 40 Number of Times each article "Focus" was used

5.3.2.3. Journals

As of March 21, 2017 articles from seventy-four different journals had been uploaded to the Tungiasis eLibrary. The journal with the most articles in the eLibrary was *Parasitology Research*. A histogram of the journals best represented in the eLibrary is shown in Figure 41. Table 16 lists the journal names for collected articles. The system of selection is not without bias since so many of the articles were discovered in the references/works cited sections of other works. The large number of articles produced by Heukelbach and Feldmeier does set up a feedback loop of sorts; every single article references at least one article authored by both. While the author could understand articles in English, Spanish, Portuguese, French, and Italian, no thorough searches in any language other than English were performed. To try to mitigate this bias the author conducted simple searches of each language's common name for the pest, i.e. "bicho de pé" in Portuguese, "nigua" and "pique" in Spanish, "jigger," and "chigoe flea," and "sand flea" in English. Unfortunately, the author cannot read anything other than the Roman alphabet, so there are dozens of languages that could not be checked.

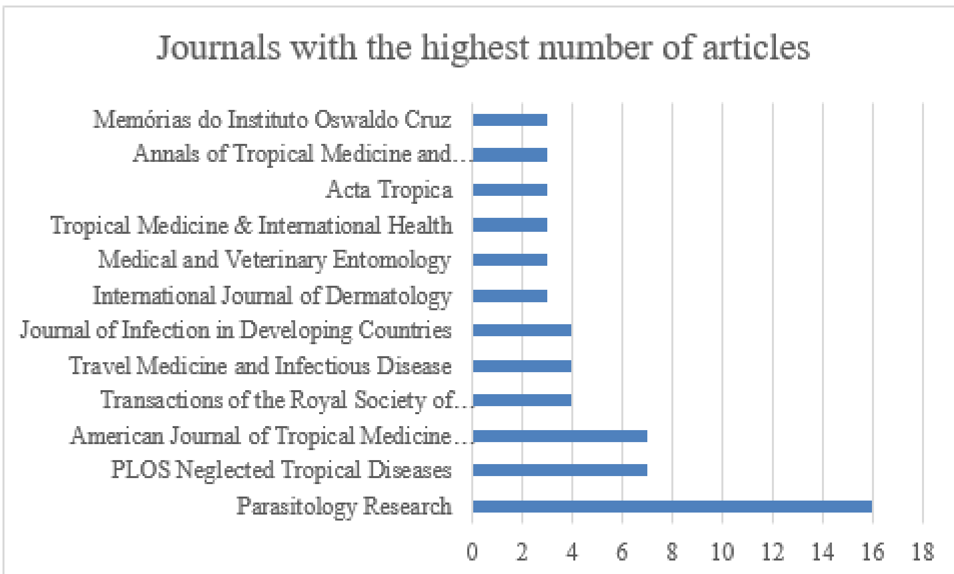


Figure 41 Top-represented journals in the Tungiasis eLibrary

Table 16 Journal Titles from the Tungiasis eLibrary

Acta chirurgica Belgica	Journal of Postgraduate Medicine
Acta Pathologica, Microbiologica, et Immunologica Scandinavica	Journal of Public Health in Africa
	Journal of the American Academy of Dermatology
Acta Tropica	Journal of the American Podiatric Medical Association
American Entomologist	
American Journal of Tropical Medicine and Hygiene	Journal of Tropical Medicine and Hygiene
Annals of Tropical Medicine and Parasitology	Malawi Medical Journal
Archivos argentinos de dermatología	Médecine et maladies infectieuses
Archivos Argentinos de Pediatra	Médecine et Santé Tropicales
BMC Oral Health	Medical and Veterinary Entomology
BMC Veterinary Research	Medical Journal of Australia
Brazilian Journal of Infectious Diseases	Memórias do Instituto Oswaldo Cruz
British Journal of Dermatology	Nigerian Journal of Parasitology
Bulletin de la Société de Pathologie Exotique	Ophthalmologica
Bulletin of the World Health Organization	Pan African Medical Journal
Canadian Medical Association Journal	Parasite Journal
Case Reports in Medicine	Parasitology Research
Ciência Animal Brasileira	Pediatric Dermatology
Dakar Médical	PLOS Neglected Tropical Diseases
Dermatology	Public Health
Dermatology Online Journal	Retrovirology
Emerging infectious diseases	Revista argentina de microbiologa
European Journal of Clinical Microbiology & Infectious Disease	Revista da Sociedade Brasileira de Medicina Tropical
Expert Review of Anti-infective Therapy	Revista chilena de infectología
Foot & Ankle International	Revisto do Instituto de Medicina Tropial de São Paolo
International Journal of Current Research	
International Journal of Dermatology	Revue de Médecine Vétérinaire
International Journal of Health Sciences & Research	Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux
International Journal of Paleopathology	
International Journal of Public and Environmental Health	Transactions of the Royal Society of Tropical Medicine and Hygiene
International Journal of Scientific research and innovative technology	Travel Medicine and Infectious Disease
	Tropical Diseases, Travel Medicine and Vaccines
Journal of Dermatology	Tropical Doctor
Journal of Environmental Science and Engineering B 1	Tropical Medicine & International Health
Journal of Infection in Developing Countries	Ugeskrift for lager
Journal of Insect Science	West African Journal of Medicine
Journal of Medical Entomology	

5.3.2.4. Year of publication

In order to encourage the linking of articles via URL or DOI, the eLibrary was populated only with articles that were discoverable on the world wide web. Thus, very few articles from before 2000 are included, with a few exceptions. The oldest article referenced in the Tungiasis eLibrary is from 1984, while the newest is from 2016. Fourteen of the 136 articles were written prior to the year 2000. The year with the most publications is 2007 with 12 publications, followed at a close second by 2004 (11), 2008 and 2011 (10) and 2009 and 2013 (9). Figure 42 shows the distribution of articles by year published.

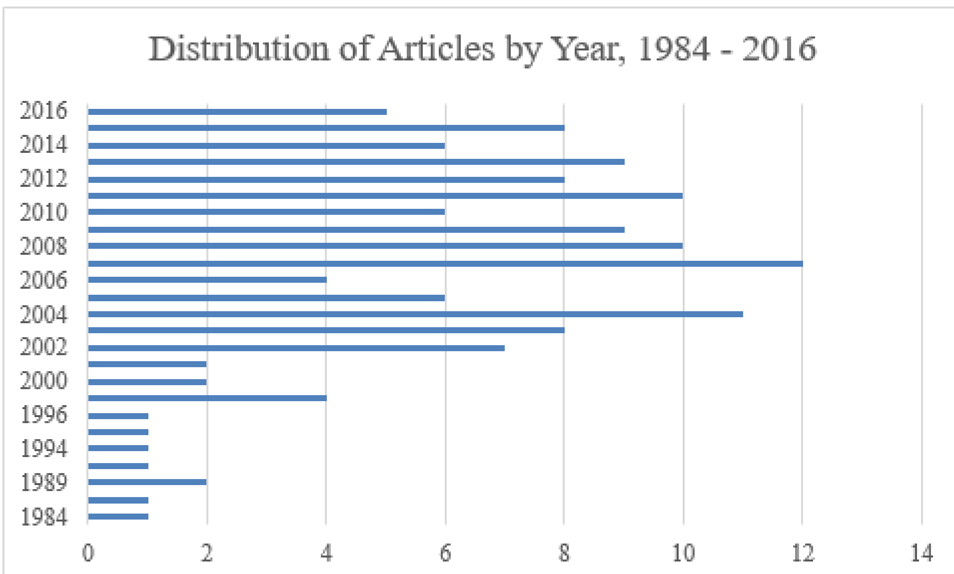


Figure 42 Distribution of Articles by Year Published

Chapter 5 discussed testing the applications, feedback from public health and GIS professionals, and performed a detailed meta-analysis of collected articles. Chapter 6 presents the final results of the application development.

Chapter 6 Results

The CFEP and Tungiasis eLibrary web mapping applications were deployed through a student web page hosted by the University of Southern California. The web addresses at the time of this writing are as listed in Table 17. The web pages were developed using Adobe Dreamweaver in Adobe Creative Cloud, a SAAS that is continuously updated for an annual fee. The web pages employed HTML5, JavaScript, and CSS to produce multi-tabbed web pages with embedded links, videos, and the main web mapping applications.

Table 17 Application and Web Page URLs

CFEP Web Page http://www-scf.usc.edu/~kawright/Chigoe/ChigoeEradication.html
CFEP App URL http://uscssi.maps.arcgis.com/apps/webappviewer/index.html?id=4563a0de487046eb8c74eccfedc94ba0
eLibrary Web Page http://www-scf.usc.edu/~kawright/Chigoe/TungiasiseLibrary.html
eLibrary App URL http://uscssi.maps.arcgis.com/apps/webappviewer/index.html?id=3f0a38ccd8c44ba7a6c4d58c4f24f6c8

Each application provides a customized mapping experience made possible by Esri's WAB application programming interface. WAB provides several out-of-box widgets to manipulate and record data into four feature classes between the two databases. The CFEP also houses an additional twenty-two layers of supporting data for use in data exploration and overlay. This chapter discusses the results of this thesis effort and addresses how the end products answer the research objectives.

6.1. Local App: Chigoe Flea Eradication Project

The CFEP is intended to be a proof-of-concept that web GIS and VGI can assist humanitarian aid workers in developing a cohesive eradication strategy for *T. penetrans* with a focus in SSA. Multiple CBOs can utilize it as a collaborative workspace with no barriers to sharing data. The CFEP ensures standardized data collection across multiple groups separated by distance, budget, or first language. Section 6.1.1. describes the study area selection. Section 6.1.2. describes the cartography for the CFEP.

6.1.1. Scope and Study Area

Because of its tropical climate, largely rural, profoundly poor population, and commonness of subsistence agriculture, Kenya is an excellent analog for other tungiasis-endemic countries. Utilizing this area for a case study enables the project to be scaled to other areas that share similar geographic and sociological attributes. There are several other advantages to choosing Kenya for this project. English is one of its two official languages, so communication with aid organizations and others within the country is not hindered with the additional burden of a language barrier. Kenya is more politically stable than other war-torn nations in the region despite increasing tension during the age of terrorism. Compared to other countries in SSA, Kenya boasts excellent data availability through its open data portal http://www.opendata.go.ke/.

Kenya's decentralized government does not have the resources or cooperation at hand to effectively address the severity of the Chigoe Flea problem. According to one recent study, Kenya boasts over 40 Chigoe flea-related relief organizations operating throughout its 47 counties (Feldmeier et al. 2013), but this author was only able to locate eight Chigoe flea-related relief organizations operating, and three of those were under the umbrella of one parent organization.

Approximately 4% of Kenya's total population suffer from tungiasis—1.4 million Kenyans. The total population at risk—10 million—are the very young, elderly, and the physically and developmentally disabled. In some communities, *T. penetrans* victims believe they have been cursed, and relatives will commonly abandon the badly afflicted. In a web video conference with the author in January 2017, Drs. Peter Keiyoro and Josephine Ngunjiri of the University of Nairobi equated the stigma associated with tungiasis with that of HIV/AIDS in many Kenyan villages. Despite the mortality rate of HIV/AIDS in Kenya, rural population density has increased considerably in the last twenty years. Coupled with the construction of roads and increasing mobility, this has led to the proliferation of uncontrolled tungiasis outbreaks (Feldmeier et al. 2013). For these reasons, Kenya served as an ideal country upon which to build the CFEP prototype. Figure 43 shows one of the final outcomes of this thesis project, the CFEP web page.

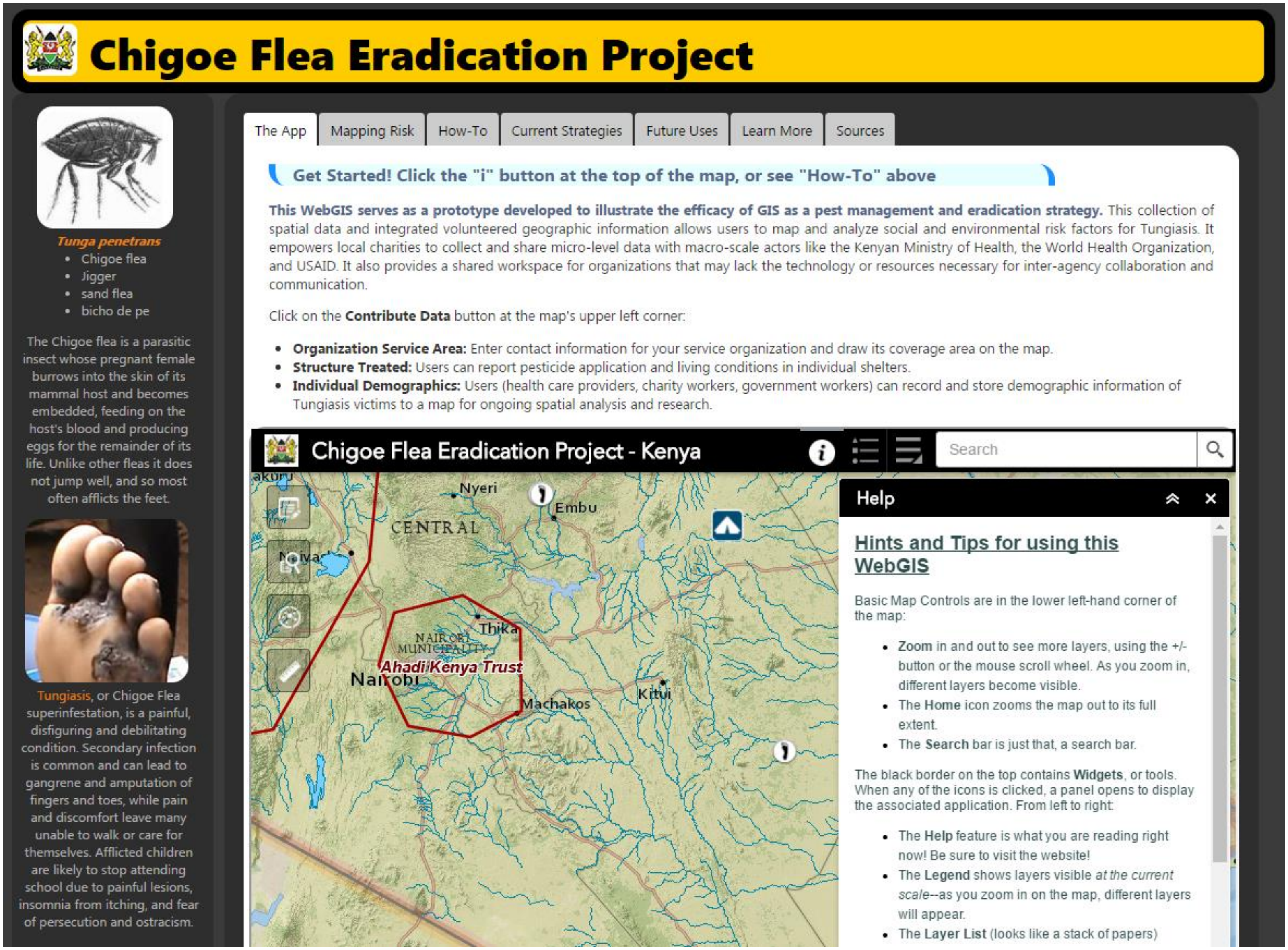


Figure 43 Chigoe Flea Eradication Project website

6.1.2. Cartography

The CFEP used the Foldable theme and National Geographic basemap. The author selected a dark theme with white text to match the website and used the Kenyan state crest as the logo icon. It is entitled “Chigoe Flea Eradication Project – Kenya” and has a byline of “capturing data, one flea at a time.” The CFEP uses symbology that conforms to KML standards. Therefore, it is fairly simple, even though Esri offers dynamic and dramatic symbology choices. Cities are symbolized as colored points of varying sizes based on population and type. The capital of Kenya, Nairobi, is a magenta-colored bullseye, while market centers are green pentagons and other villages look like brown wagon wheels. In retrospect, this cartography is unneeded. The underlying Esri basemap—in this case the National Geographic basemap—shows most of those villages and outposts at different zoom levels, with dynamic labels. The CFEP School layer was symbolized using an international symbol for schools, a small rectangle with a flag on top. Hospitals and medical facilities were all symbolized based on a variation of the universal symbol of the blue cross. Figure 44 shows the symbology used for the CFEP supporting point datasets.

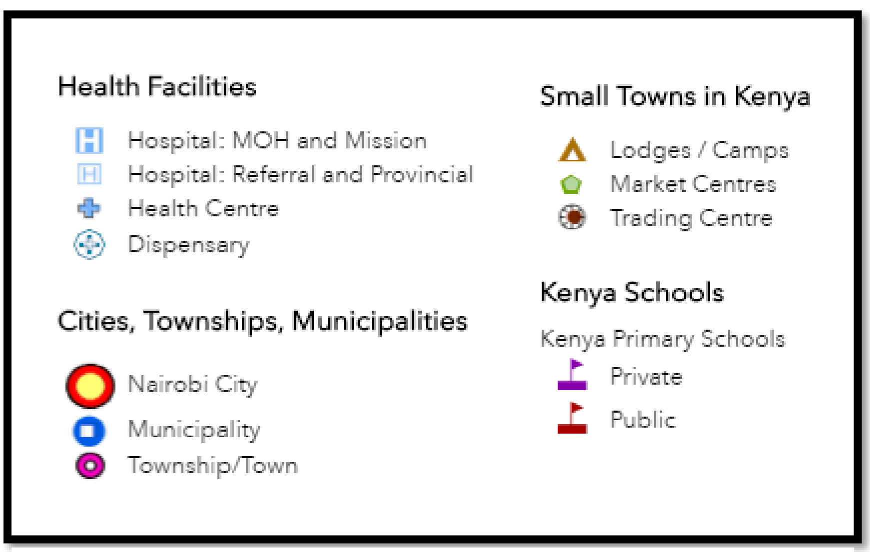


Figure 44 Point Symbols in CFEP Supporting Data

Of the three VGI datasets, two are point datasets while the third delineates polygons. The *Individual_Demographics* feature class is symbolized as a stylized footprint within a circle. The *Structure_Treated* feature class is symbolized by a stylized white tent/sleeping shelter on a blue rounded rectangle. The *Service_Areas* polygons are clear with a wide dark red line. These symbols were deliberately chosen to be bright enough to show up on a digital map. For the sake of the prototype these datasets are visible at the national scale and below. In a future real-world deployment this author recommends that the two point feature classes only display at local scales until enough areas have been surveyed to use the point features as an epideiological distribution. Figure 45 shows the symbology chosen for the CFEP VGI layers.

Figure 45 Symbology for CFEP VGI Datasets

Line and polygon features in the CFEP are symbolized in a variety of ways. Perhaps most surprising to the author was the case of the moving boundaries discussed in the Challenges section of Chapter 7. Because there were so many different boundary datasets for Kenya, the author had to come up with a way to differentiate between what ended up being eight different boundary layers which were rarely coincident (not only politically, but there was an obvious datum shift in at least one layer). Figure 46 shows the resulting symbology used for Kenya's changing administrative boundaries.

Figure 46 Symbology for CFEP Administrative Boundaries

Lastly, symbols had to be selected for polygon areas of malaria endemicity, a DEM, and a rainfall isopleth. Malaria endemicity was symbolized based on its severity; in areas that are highly prone to epidemics, bright reds and oranges are used, while low-risk areas are mapped in a light gray. A hypsometric tint was used for the DEM to visualize the elevation of the area. The

Rainfall isopleth used a large number of classes in the interest of maintaining regular intervals (2-11, 12-21, 22-31, etc.) and to provide for a smooth color gradient from “dry” to “wet.” Figure 47 illustrates the selected symbology for these layers.

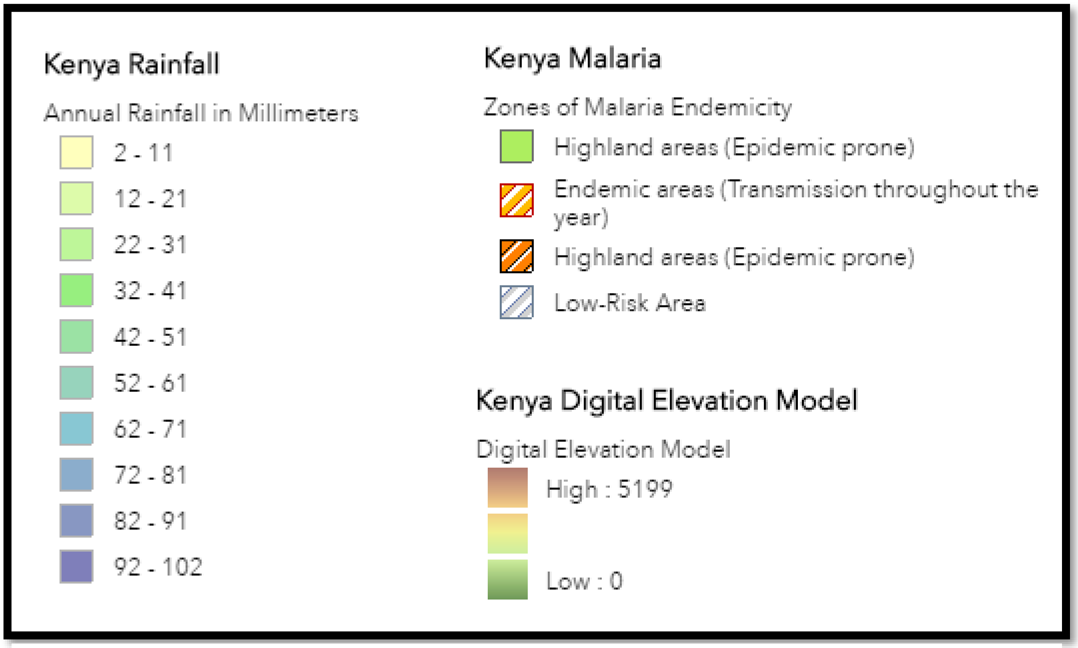


Figure 47 Symbology for CFEP Layers: Malaria, Rainfall, DEM

Section 6.1 discussed the final output of the CFEP, including the website, WAB theme, and web cartography. Section 6.2 does the same in kind for the Tungiasis eLibrary.

6.2. Global App: Tungiasis eLibrary

The experience gained developing the CFEP contributed to the development of the Tungiasis eLibrary. The author copied the website (notice the similarities between the CFEP and eLibrary website, shown in Figure 53) almost exactly but improved upon some aspects of the application. Section 6.2.1 describes the interface and cartography of the eLibrary. Section 6.2.2 discusses the data and layers within the Tungiasis eLibrary. Figure 48 is a landscape-formatted figure showing the Tungiasis eLibrary website and its embedded web mapping application.

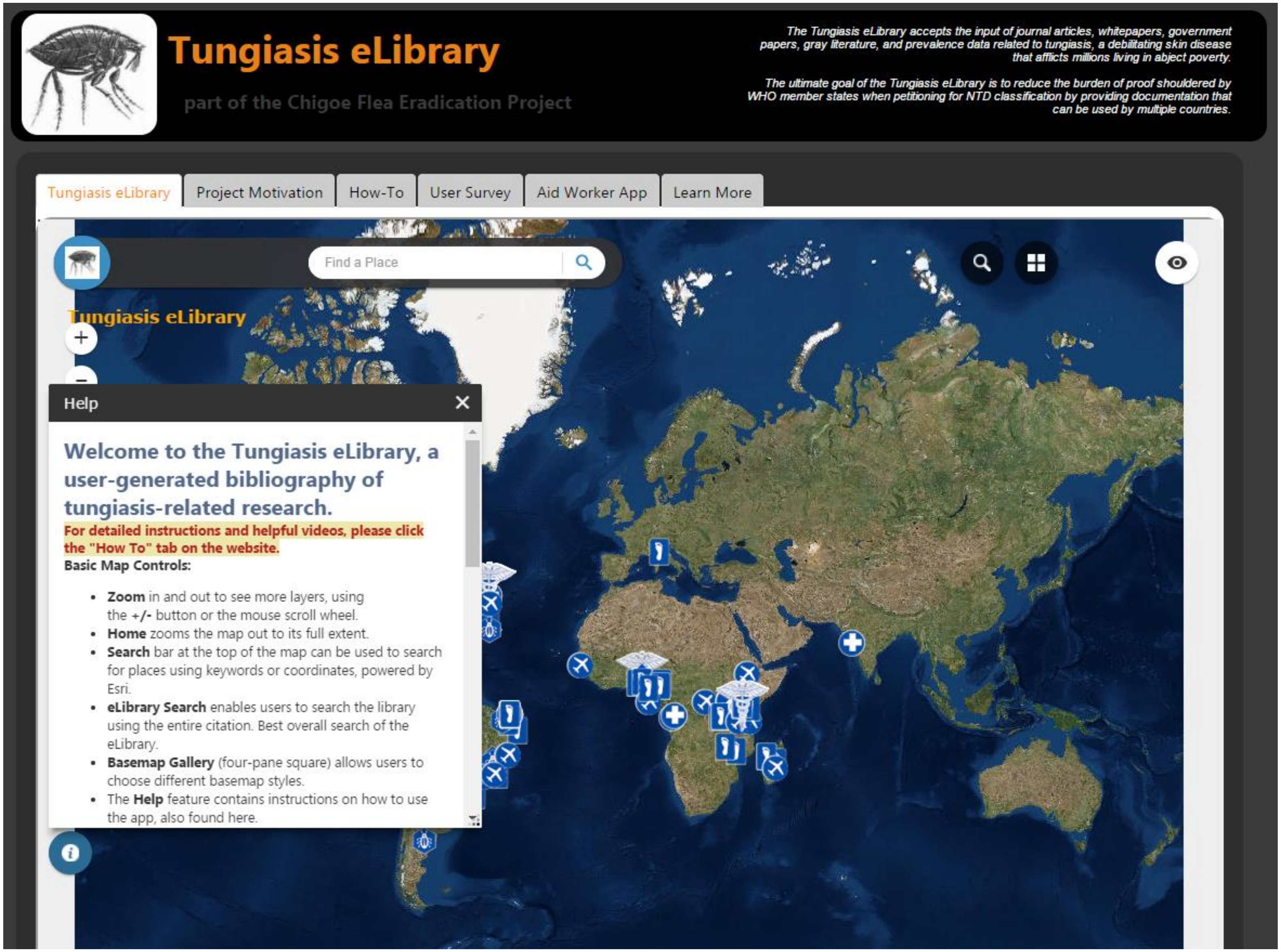


Figure 48 Tungiasis eLibrary Website

6.2.1. Interface and Cartography

The Tungiasis eLibrary is intended to be used at a global scale and opens to an imagery basemap of the world. The dark theme is consistent with the CFEP, and the logo icon is an image of *T. penetrans* from a Kenya MOH government paper (MOH 2014). It is entitled "Tungiasis eLibrary" and has a byline of "A user-generated bibliography of tungiasis-related literature and data." There are no administrative boundaries, suggesting this is a planet-wide problem. Viewing the data at this scale enables the user to see the distribution of articles, also suggesting the spatial distribution of the pest and tungiasis. Like the CFEP, it was important to make sure that symbols could be exported as KML, so the icons are crafted to show each article's focus. All icons are white on royal blue and can be seen in Figures 37 and 53. The Survey or Study focus is symbolized with a bare foot, while Information is symbolized with a lowercase i. Medical focus is symbolized with a white cross on a round blue circle. Traveler icons show the silhouette of an airplane, and Veterinary icons are blue diamonds with a silhouette of a rat. The symbol for Entomology/Biology is a white insect on a blue hexagon. Lastly, Spatial Data focus is symbolized with a white compass rose on a blue background, and is very much larger than other icons. (No spatial data has yet been volunteered to the eLibrary.)

The symbols were chosen with great care, but they do look a little unprofessional. The author did succeed in the purpose of making a set of icons when, viewed at a distance, suggest a common feature, thus creating a spatial distribution of tungiasis at large. Their similar sizes and same color was intentional so that they would appear as a single, cohesive dataset.

The operational widgets in the Tungiasis eLibrary are accessed through the Launch Pad at the bottom center of the app. Figure 49 in the next section shows the Launch Pad of the Tungiasis eLibrary. From left to right, the widgets are Legend, Layer List, Browse for Articles

(Query), Contribute Data (Smart Editor), Select and Export, and Bookmark. Using WAB totally out-of-box, there was no choice of icon color. Since the author wanted to be able to color-code the buttons to the text in the Help widget (as seen in Figure 37), the default colors were used. If the theme color is custom, the icons convert to an all-gray scheme and cannot be recolored. Each of these widgets is described in detail in section 6.3, Widgets and Workflows.

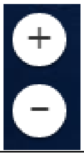
6.2.2. Additional Widgets

Adhering to the concept of "less is more," this web mapping application tries to keep its functionality simple. Using the out-of-box interface and widgets from Esri's WAB, users can browse the Tungiasis Bibliography, view pre-set queries to explore the data, and then volunteer data by contributing articles and unpublished work. These workflows were detailed in Section 5.1.2. This section lists the remaining widgets used in the Tungiasis eLibrary. On-map controls include Zoom, Home (extent), the Find a Place Search bar, eLibrary Search, Basemap Gallery, the Help Widget, and the Attribute Table button. These basic map controls' icons are outlined in Table 18.

The Launch Pad at the bottom of the map contains widgets, or in-app functions, represented as round icons. Figure 49 shows the Launch Pad. The first two widgets are the Legend and Layer List. The Legend widget displays a key for layers visible at the current scale; as the map is zoomed in, different layers appear. The Layer List widget displays all data layers contained in the web application, including layers that are currently turned off.

Figure 49 Launch Pad of the Tungiasis eLibrary

Table 18 Basic Map Controls

	**Zoom** in and out using the **+/-** button or the mouse scroll wheel.
	The **Home** icon zooms the map out to its full extent.
	The **Find a Place** Search bar can be used to search for places using keywords or coordinates, powered by Esri's World Geocoder service.
	The **eLibrary Search** enables users to search the library for articles by primary and secondary focus, author, title, country, journals, or citations. This is the best tool to use if trying to locate articles by authors that are not listed first.
	The **Basemap Gallery** allows users to choose different basemap styles.
	The **Help** feature contains instructions on how to use the app.
	To explore all **Attribute Tables**, click on the icon that looks like a table.

Checkboxes to the left of each layer indicate which layers are turned on. To prevent clutter on the map, many layers are turned off by default. Some layers are only visible at certain zoom levels. For example, the analysis layers detailing numbers of articles by country and home country of author are not visible when zoomed in to a local level.

The Chart widget has three pre-set queries that are plotted on various chart types. Users can explore Articles by Country of Study as bar and pie charts showing the distribution of articles by country of study, or Articles by Country of First Author. These pie and bar charts describe the distribution of articles based on the home country of the first author of each paper. Within the NTD research community, primary authors often do not live within the country they are studying. This is discussed in greater detail in Chapter 5. The Articles by Author bar chart functionality reveals the most "prolific" authors within the tungiasis research field (Jörg

Heukelbach and Hermann Feldmeier). Each chart can be filtered spatially; that is, a user can zoom to a particular region and use the Chart widget to plot articles only from the visible extent.

The Select and Export widget offers users another way to select and export data beyond the Browse Articles widget. Users can draw a box around desired points on the map and batch export to multiple file types, including CSV, feature collection (feature class existing outside a geodatabase), or GeoJSON. Figure 50 shows the Select and Export widget interface.

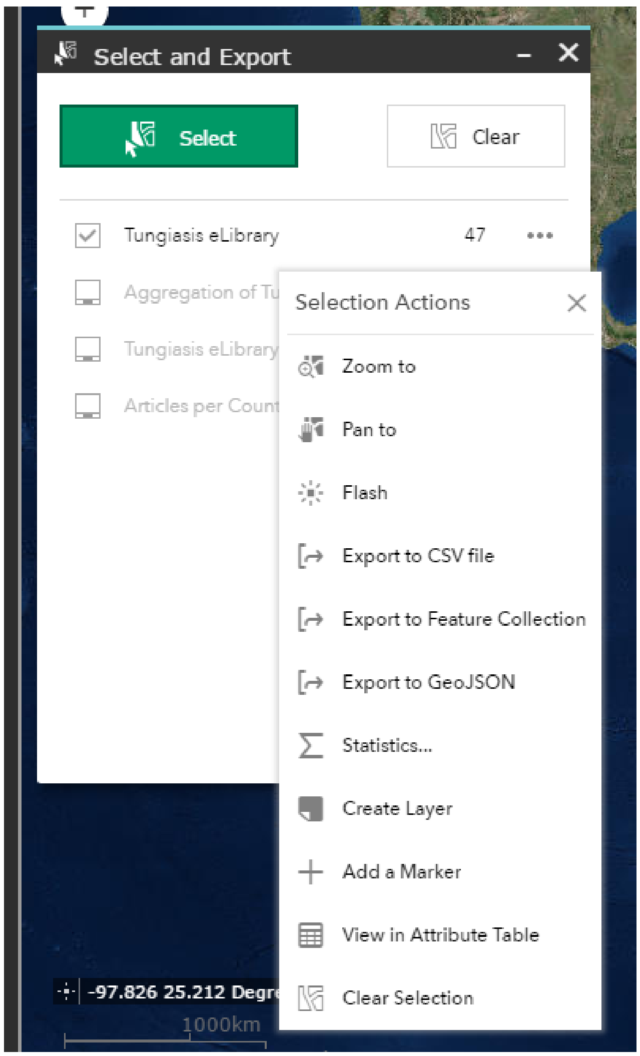


Figure 50 Select and Export widget interface

The Bookmark widget opens a list of bookmarks providing users with locations of interest on the map and enables users to create their own bookmarks for rapid map navigation.

Chapter 6 discussed the results of the thesis study, including descriptions of the finished applications. Chapter 7 concludes the thesis with suggestions for future work and draws conclusions about the thesis objectives.

Chapter 7 Conclusions and Future Work

The success of this project can be measured against the thesis research objectives stated in Chapter 1. Section 7.1 revisits the objectives and discusses in what ways they have or have not been met. Section 7.2 describes problems encountered and challenges faced in research and development, while the most important limitations of the applications are outlined in Section 7.3. Lastly, Section 7.4 discusses future work and the adaptability of the applications to different geographies and topics.

7.1. Revisiting Thesis Research Objectives

The CFEP was developed as a proof-of-concept for using web GIS as a collaborative workspace for the management of a serious pest or debilitating disease. The Tungiasis eLibrary was developed to provide a body of evidence for the reclassification of tungiasis as a NTD. Both inspire activism at local and global levels, and both utilize VGI to perpetuate those goals. In this project Web GIS became a “place” where people across the globe can work together, share information, and function despite the politics of bureaucracy or the vast geographic and socioeconomic distances between them. This section revisits the thesis research objectives from Chapter 1, and discusses how the development of these two apps satisfies those objectives.

7.1.1. Objective 1: Curate Literature Collection

The first thesis research objective was “Curate an exhaustive collection of peer-reviewed scientific literature pertaining to tungiasis and *T. penetrans*.” A prolonged, thorough search for that literature resulted in 132 documents, forming a bibliography. Each article was georeferenced to the location of study. This collection of georeferenced literature, augmented by VGI of newly-written research, is intended to serve as the required dossier of evidence for countries who wish to petition the WHO to reclassify tungiasis as a NTD. Additionally, all 132 articles are linked to the original work, adding to the legitimacy of the collection. The collection includes articles from five different languages: English, Spanish, Portuguese, French, and Italian. It includes articles from multiple disciplines: Epidemiology, Entomology, Public Health, Medicine (and Travel Medicine), and Veterinary Science. It includes government and NGO publications, and articles authored in 25 different countries. The collection is certainly not "exhaustive" as the author encountered several other articles about tungiasis during application development. In truth, the notion of "exhaustive" shouldn't be applied to an interactive bibliography designed to be continuously updated. Overall, the first research objective has been achieved by the Tungiasis eLibrary.

7.1.2. Objective 2: Develop a Global Spatial Distribution of Tungiasis

Adding a spatial component to each article and plotting those points on a world map add value to the bibliography. Instead of just being a collection of 132 articles, there are now 132 data points on a map that when viewed at a global scale show a propensity for the tropics. Even after subtracting the sixteen articles classified as "without country," there are 116 relevant data points in the Tungiasis eLibrary dataset. Also, the Tungiasis eLibrary comprises a spatial dataset that when plotted produces a spatial distribution of tungiasis and *T. penetrans.* This result of georeferencing the articles represents the first-ever spatial visualization of the distribution of *Tunga penetrans*, thus fulfilling the second thesis research objective.

7.1.3. Objective 3: Develop, Publish, Test and Promote

The third thesis research objective was to "develop, publish, test and promote purpose-built geodatabases for each application with VGI and supporting data." One app should enable local, on the ground epidemiological data collection, while the other should be a literature collection to aid in global policy change. Esri software and applications were used to construct each geodatabase, create and publish map and feature services, create and share web maps, and develop the finished web apps. The CFEP fulfills the objective of data collection, and demonstrates how easily web GIS can cater to different projects. The Tungiasis eLibrary fulfills the objective of housing a literature collection with the intent to change global disease classification.

The Tungiasis eLibrary was tested by at least ten users, not including the author. The workflows to browse literature and contribute data do function as intended. The CFEP has been live since early 2016 and one public health researcher, Dr. Lynne Elson, found the application and used it to enter her aid organization's service area and contact information, and later contacted the author through an email address (ChigeoFleaEradicationProject@gmail.com) listed on the CFEP website. While the CFEP is capable of ingesting individual demographics and pesticide treatment records, until issues of patient privacy (discussed in Chapter 2) can be addressed to the author's satisfaction, the CFEP will not be deployed for data collection. Because of this, the author deliberately declined to promote that ability due to concerns of patient privacy and project longevity. However, the author did promote the CFEP and Tungiasis eLibrary by presenting at four different conferences. The author was invited to present the CFEP and eLibrary at the 2016 and 2017 Esri Developer Summits, respectively (Wright 2016a, 2017a). As a result of the 2016 presentation, the author was featured in Esri's *ArcUser* Magazine (Stevens 2016) and USC's newspaper (Bell 2016). At the American Association of Geographers annual meeting in 2016 the CFEP was presented in the Cartography Specialty Group's graduate student paper competition (Wright 2016a), and was scheduled to have been presented at that year's

Geospatial Health Symposium. The author was again invited to present at the 2017 Esri DevSummit (Wright 2017b) and was selected as USC's EDC Student of the Year for 2017 for work on the CFEP and Tungiasis eLibrary apps. As a result of that award the project was entered into Esri's International EDC Student of the Year competition, and was selected as one of the top ten featured in an Esri GeoNet article (DiBiase 2017). The author also presented the Tungiasis eLibrary at the AAG 2017 annual meeting's Geospatial Health Symposium. Thus, the thesis research objective of promoting, publishing and testing was achieved.

7.1.4. Objective 4: Develop Website and Document Workflows

The websites http://www-scf.usc.edu/~kawright/Chigoe/TungiasiseLibrary.html and http://www-scf.usc.edu/~kawright/Chigoe/ChigeoEradication.html were developed to house the apps and provide relevant information about tungiasis, NTDs, WHO policy, and diseases of neglect. The skills to develop web pages using HTML5, JavaScript and CSS were obtained in the graduate course SSCI 591 Web GIS taught by Dr. Jennifer Swift. The CFEP website was live as of January 2016. The eLibrary webpage was developed in October 2016. Both sites have detailed instructions for using the apps, and the eLibrary also has sample data to test the "Contribute Data" widget. Two Jing screencasts were made to demonstrate how to use the eLibrary, detailing the "Contribute Data" and "Browse Articles" widgets (links to screencasts on the website). Additionally, each application contains a "Help" widget explaining workflows and directing users to the longer help texts on the websites. This thesis objective is fulfilled by the Tungiasis eLibrary and CFEP websites.

7.1.5. Objective 5: Employ Esri Technology

Chapter 3 thoroughly documented the technology used to develop and deploy the applications, utilizing a sizeable number of Esri applications. An enterprise geodatabase was housed on a virtual server machine provided by USC's SSI with ArcGIS Server 10.3, where map and feature services were stored for consumption in AGOL web maps. Those web maps were in turn consumed by the CFEP and eLibrary apps. USC's status as an Esri Development Center means that students have access to the latest and greatest Esri technology and support, so this thesis objective was achieved.

7.1.6. Objective 6: Demonstrate Web GIS Fitness for Disease and Vector Management

This is the most difficult research objective to call "done." The last thesis research objective was to "demonstrate the unique fitness of web GIS for disease and vector management." The apps generated considerable interest in the tungiasis field. In fact, the author was contacted by four tungiasis researchers working in SSA who wish to collaborate in the future and are excited that both apps exist. The Future Work section later in this chapter discusses the adaptability of the CFEP database design to other pests, parasites, disease vectors and invasive plants and animals, which demonstrably achieves this last thesis objective.

7.2. Problems Encountered During Development

As with any program development, many problems were encountered and many challenges were faced. On the development side, there were software changes at the university and procedural changes to virtual machine and AGOL access that reduced effective working time on this project. Websites were redesigned and restructured while the author was writing this thesis, as many retired links from previous USC SSI coursework and syllabi stopped working.

Additionally, there were several Esri bugs encountered during development that slowed progress on the thesis project, discussed in earlier chapters.

Certain policy and procedure snags were also encountered. An outdated email address (that was still accepting email) was not being checked by the institutional review board, which added several weeks to the institutional review board review process; the end result was that no review board process was required for this thesis work. After the author was provided with a virtual machine (VM) for SSCI 591 Web GIS, GIST program changes meant that the entire process to create a server changed dramatically at the time the bulk of the thesis work was initiated. Despite updated documentation, the author was not able to successfully publish map layers using the revised system architecture. At the same time, the university migrated to organizational access for AGOL, but the entire CFEP project completed to date was tied to the technology provided as part of a SSI 591 Web GIS class section from Fall 2015. There was no clear path to unite both AGOL accounts so that the author could migrate the maps and apps from the SSI 591 account to the new institutional access. Because these problems precluded development for several weeks, it was decided that the author's AGOL access and VM settings would be left as-is for the remainder of time working on the thesis at USC. To log into the VM, USC SSI's virtual private network (VPN) was accessed with the Cisco AnyConnect Secure Mobility Client. A remote desktop connection was established with the VM which acted as a server for both projects. Despite the seamless technology provided, using ArcGIS Desktop on the VM was slow relative to a local installation.

From a best-practices standpoint, this thesis project taught the author many lessons. For example, over a third of the fields in the Individual Demographics feature class could have been fed with one domain of Yes or No. Instead, the author created separate Yes/No domains for at least six fields. Also, duplicate entries were accidently recorded in the CFEP VGI tables. Although this is considered bad data management, these were trial data entries intended to be individual VGI datasets serving as proof-of-concept, so they stood individually. The author wanted to provide a good representation of what types of questions would be asked in the three different scenarios. In practice, it would be imprudent from a data normalization standpoint to record all this data twice (i.e. distance to water, waste disposal) because this violates database normalization rules by recording redundant data. This causes problems when one dataset is updated and the other does not; both datasets must be updated to maintain data integrity.

7.2.1. Data Problem: Boundary Fluidity

A significant problem occurred regarding administrative boundaries encountered when developing the CFEP. International boundaries are surprisingly fluid; it is not uncommon in SSA and South Africa for neighboring countries to dispute each other's claims to a particular region. Thus, at the sub-national level it is difficult to locate a GIS dataset that can be considered authoritative. Additionally, consider the example of constitutional change within Kenya: dramatic changes in administrative boundaries have occurred over the last twenty years due to elections and constitutional changes. The Ministry of Planning and National development, Central Bureau of Statistics authored a brief history of the census in Kenya, outlining the inherent problems in mapping a region in political flux (Odhiambo and Ndilinge 2005). The legacy system of Provinces, Districts, Divisions, Locations, and sub-locations was continuously updated for over ten years, meaning that GIS datasets produced in Kenya from 1995-2013 had widely varying administrative boundaries. For example, the 1999 census reported 6,612 sub-locations in Kenya, each with its own form of government home-rule and own local understanding of its borders. This variance in enumeration units continues to make spatial analysis difficult. And a lack of established standards in data collection over this period resulted in the production of many datasets that are now functionally obsolete. Therefore, it is of the utmost importance to consider the dates and administrative boundaries in use when data was collected in geographic areas of political unrest or rapid governmental growth.

To better illustrate this phenomenon and to allow for data comparison within the correct administrative units, multiple datasets of Kenyan boundaries were integrated into the CFEP. A 2009 Kenya administrative boundary dataset was downloaded from DIVA GIS, owned by the University of California, Davis, which differed from other boundary datasets hosted by the World Resources Institute and the International Livestock Research Institute, showing 2000 and 2013 boundaries. To provide a shapefile with which to join tabular data, this project used FLAU boundaries from the most current GADM database of Global Administrative Areas.

7.3. Limitations

Web GIS does have limitations, and so do the CFEP and eLibrary apps. The way the CFEP database was designed, only one concurrent health condition can be recorded per individual, which is counterintuitive since comorbidity of NTDs is so high. Patient privacy is a serious concern in a real-world application, so security measures would need to be taken such as removing personal identification from the data or storing it on secure servers using HTTPS. In fact, *not* using HTTPS prevents the "locate me" widget native to all WAB apps from functioning, which is a major limitation for WAB development in developing countries where HTTPS may not be a web standard. Even if the widget does function, however, the WAB format requires user interaction with the map; that is, users must manually place data points on the map. The CFEP does not use a mobile device to record a GPS point. Collector for ArcGIS, for example, could be employed to collect real spatial data in the field. Lastly, these WAB apps do not have offline functionality.

The CFEP's name itself is a limitation—the author realizes now that *Tunga penetrans* will never truly be eradicated. In retrospect, the app could be called the Chigoe Flea Management Project. In Chapter 1 it was noted that archaeological evidence places *T. penetrans* in Peru 1400 years ago—extinction is unlikely at best, especially given its wide range of hosts. Lastly, it must be noted that the biggest limitation to using these apps in the field in SSA is the technological requirement of obtaining a mobile device and being in an area with adequate cellular data network coverage. As discussed earlier, the Collector app for Android and iPhone could resolve this issue and make data collection possible even without a cellular data connection.

7.4. Adaptability

A geographic information science approach to the control of parasites and/or introduced and invasive species has many applications as we continue down the path of becoming a global society. In addition to applying the CFEP or eLibrary model to other neglected diseases, these models are equally effective for invasive and exotics species, blights, and viruses. Parasitic insects have long threatened the safety and well-being of humans. Developing a strategic GIS for the identification of infestation and creation of a treatment plan—be it the use of pesticides, distribution of medicines or prophylactics, or scheduling of medical visits—will be essential for combatting the scourge of human ectoparasites that act as disease vectors in densely populated areas. Just as invasive plants, reptiles, and mammals colonize new lands through unintentional introduction, so do pests and parasites. These pests cost us both economically and socially, supporting the need to explore new, effective management strategies for their control and removal. The potential for future use of this model in managing pests that negatively impact human life is wide-ranging in the management and eradication of many economically destructive and disease-propagating pests:

- Programs to control or eradicate the invasive Red Imported Fire Ant (RIFA), *Solenopsis invicta* in the United States, Australia, Taiwan, and China
- Continued work toward the prevention and elimination of malaria by studying distribution and biology of *Anopheles stephensi* mosquitos, recording areas targeted with pesticide application, and tracking the distribution network of materials such as mosquito netting and anti-malarial medications
- Efforts to reduce the worldwide economic and ecologic impacts of the invasive Formosan subterranean termite *Coptotermes formosanus* and Asian subterranean termite *C. gestroi* as the two species now readily hybridize (Chouvenc et al. 2015)
- Studies to track the spread of Africanized honey bees *Apis mellifera scutellata* in the western hemisphere, and research into the decline of European (Italian) honey bees *A. m. liqustica*
- Education and prevention efforts in tropical Africa toward the extermination of mangoworms, *Cordylobia anthropophaga*, a species of blow-fly causing myiasis in both humans and animals
- Management and prediction of the spread of Dutch Elm Disease (DED) in North America and Europe caused by an invasive fungus spread by three species of bark beetle in the family Curculionidae

- Establishment of a plan of action to address rapid expansion of the recently-introduced brown marmorated stink bug *Halyomorpha halys* in the United States
- Addressing the ongoing catastrophic spread of the Pine Bark Beetle across North American pine forests

The web GIS platform is adaptable to geographic location, as well. Limitations on that adaptability would rely on the existence of supporting geospatial data, which in some countries is not readily available. The CFEP displays the scalability of web GIS; the web map and web app format provide the user with a rich two-way experience that enables data exploration and collection at an unlimited number of scales.

7.5. Future Work

The author hopes to continue working on improvements for the CFEP and Tungiasis eLibrary apps, and has plans for collaboration with tungiasis researchers in the future. This section discusses future work in app development and functionality, and concludes this thesis project and manuscript.

To customize the apps, the ArcGIS API for JavaScript could be used to change pop-up behavior, create custom widgets, and change the look and feel of the apps or their mobile interfaces. The author hopes to make the apps offline capable, and will investigate Esri's Collector app and/or Survey123 to facilitate data collection in the field (Esri 2017e, 2017f). Python programming could be used to create a geoprocessing service to run in the background that would feed the charts and aggregated analysis layers in the Tungiasis eLibrary as more data points are added. Additionally, a true full-text search of the linked articles would be a boon. At the time of development, Esri did not have a Tag widget built into WAB. To build a more comprehensive metadata, tagging should be required for article submission. This would make the database searchable by keyword, and could build connections between research that might not otherwise be clear. It is surprising a Tag widget does not already exist—tagging is required when uploading data and layers to AGOL, and social media makes use of tagging for people and places. Twitter hashtags can also be considered tags, so it can be assumed that users will be familiar with the process.

Additional desired CFEP and eLibrary functionality:

- Programming to address the important issue of patient data privacy
- Implement an RSS Feed for when new articles are added to the DB
- Provide article abstracts like GIDEON, PubMed or PLOS
- Enable text or metadata extraction using optical character recognition of PDF documents or linked websites hosting the article
- Add an animated GIF of "have you seen our quick tutorial" just above the map line on IMF eLibrary: http://www.elibrary.imf.org/
- Add the ability for users to rate the data points for accuracy or usefulness
- Add authentication requirement for viewing CFEP data (when patient data begins to be uploaded)
- Allow articles that have more than one location be represented by a multipoint feature

Section 7.1 reiterated the thesis research objectives and addressed how the CFEP and eLibrary apps achieved those objectives. Section 7.2 discussed challenges faced and problems encountered while developing the two apps. Section 7.3 addressed several of the limitations of the two apps, and Section 7.4 detailed several different research topics that the CFEP app could be applied to. Lastly, Section 7.5 suggested future work for the project.

By developing the CFEP and Tungiasis eLibrary apps, the author intends to spur further conversation within the field of public health about different ways that web GIS can be applied to combat diseases and manage the vectors that cause them. Should a WHO member state be ready to take the step to petition for NTD classification of tungiasis, the eLibrary is poised to serve as both dossier and spatial distribution for that cause. Even if nothing else comes from the development of these apps, the idea of web GIS has been introduced to the tungiasis researcher community, and members of the GIS community are thinking of new and innovative ways to apply GIS to humanitarian aid efforts.

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Appendix A Chigoe Flea Eradication Project REST Service Endpoints

Service Name	REST Service Endpoint
Organization Service Area	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Service_Area/FeatureServer/0
Individual Demographics	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Individual_Demographics/FeatureServer/0
Structure Treated	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Home_Visit_Record/FeatureServer/0
Health Facilities	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Health_Facilities/MapServer/0
Cities, Towns, Municipalities	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Kenya_Cities/MapServer/0
Small Towns in Kenya	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Kenya_Cities/MapServer/1
Kenya Counties – 2014	http://591-kawright.usc.edu:6080/arcgis/rest/services/Kenya_2014_Boundaries/MapServer/0
Kenya Hydrology	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Kenya_Rivers_Lakes/MapServer
Rivers – AFRICOVER	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Kenya_Rivers_Lakes/MapServer/0
Lakes – ILRI	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Kenya_Rivers_Lakes/MapServer/1
Kenya Former Boundaries	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Kenya_Former_Boundaries/MapServer
2009 Admin Boundaries	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Kenya_Former_Boundaries/MapServer/0
National Boundary - 2009	http://591-kawright.usc.edu:6080/arcgis/rest/services/Chigoe_Flea_GIS/Kenya_Former_Boundaries/MapServer/1