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INVESTIGATING WATER ACCESS CHALLENGES FOR EMERGING AND DEVELOPING COUNTRIES: VIETNAM AND KENYA CASE STUDY

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ABSTRACT

The United Nations member states outlined 17 Sustainable Development Goals (SDGs) to accomplish by 2030 to better the world that cover a broad range of topics such as poverty, the environment, and infrastructure. Engineering disciplines are applicable to many if not all of these goals, since engineers often strive to develop innovative solutions to the world's biggest problems. One of the most basic human rights is access to safe drinking water and sanitation, a responsibility which the 6th SDG strives "to ensure access to water and sanitation for all."

In order to build further understanding of the complexities that exist within international development and ensuring equal access to safe drinking water, the objective of this thesis is to investigate specific water access challenges for developing and emerging countries, specifically in Vietnam and Kenya. The questions guiding this research are: What are the current challenges that exist in ensuring equal access to safe drinking water for all? How effective are certain mitigation efforts in Vietnam and Kenya? How can engineers and policy makers contribute to improved access to drinking water? Within this thesis, Chapter 1 presents an overview of the current challenges that exist within water access. Chapter 2 and 3 are case studies detailing specific filtration techniques used in Vietnam and Kenya, respectively, to determine their efficacy at *Escherichia coli* removal. After presenting these cases, Chapter 4 presents some scientific conclusions surrounding this research and next steps that can be taken. Finally, Chapter 5 outlines personal reflections and takeaways from composing this thesis.

This research is valuable because if we can better understand the current state of water access in developing and emerging countries, we can better identify where research is lacking and future steps that need to be taken.

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Chapter 1

Universal Safe Access to Water

In 2015, United Nations (UN) Member States adopted "The 2030 Agenda for Sustainable Development" which outlines 17 Sustainable Development Goals (SDGs) to ensure peace and prosperity for all people and the planet. These goals strive to improve health, education, equality, and the economy in order to end global poverty (1). All countries have been tasked with these calls for action, forming a global partnership to benefit the world. Engineers, specifically, have a crucial hand in making these goals a reality. Sustainable development focuses on the "triple bottom line" concept, aiming for harmony between economic development, environmental sustainability, and social inclusion; profit, planet, and people (2).

The SDGs are a successor to the UN's eight Millennium Development Goals (MDGs), targets for the year 2015, that are reported as "the most successful anti-poverty movement in history" (3). Despite many successes, some goals also fell short of their desired outcomes. The failures were a learning experience as it provided the UN with vital information on what they know how to do well and what they need to improve on. Long-term effort along with support from policy makers will be needed to address the root issues of poverty, Further progress can only be made by integrating economic, social, and environmental development. The new SDGs reflect what was learned and will help facilitate putting all countries on track towards a more prosperous world (3). The literature review that follows will provide an outline pertaining to the complex issues surrounding universal safe water access. Topics such as the SDGs, global engineering challenges, and progress towards achieving SDG 6 regarding universal and equitable access to safe and affordable drinking water will be discussed.

Global Engineering Challenges

The SDGs provide a framework for specific global needs to ensure safety for all. As engineers dive into the challenges associated with each of these goals, there are a few major engineering challenges that stand out. Going beyond the United States, engineers must be trained to solve problems in countries worldwide. Developing and emerging countries will account for 95% of the 2 billion people that are estimated to add to the population in the next 30 years (4). Major challenges for engineers include the need to improve sustainability, reduce our carbon footprint, and identify feasible alternative energy sources. Other global engineering challenges include improving technology to prevent cyberattacks to protect personal data, wealth, and government knowledge (5). The SDGs outline these, and many other, global challenges where engineers can contribute to addressing the most prominent and daunting needs of the world.

For engineers whose training has been focused on design and building in developed countries, there may be simple basic rights that many people in the developed world take for granted. Imagine if every trip to obtain drinking water took longer than 30 minutes. Imagine not being able to attend school because the proper infrastructure simply does not exist. These scenarios are the reality for millions of people and the SDGs take steps to solve these global issues related to water, energy, climate, oceans, urbanization, transport, science, and technology.

SDG 6

Undeniably, one of the most basic human rights and needs is safe drinking water. The 6th Sustainable Development Goal states the aim to “Ensure access to water and sanitation for all.” Millions of people die every year because of diseases contracted from unsafe water, sanitation, and hygiene (6). Having access to safe drinking water is critical for human health and translates to economic development, gender equality, and poverty reduction. Despite these explicit goals, according to the United Nations

International Children's Emergency Fund (UNICEF) and the World Health Organization (WHO) as of June 2019, 2.2 billion people still do not have safely managed drinking water services, including 144 million people who drink untreated surface water (7). For at least one month of each year, half of the world's population already faces severe water scarcity (8). Every day, around 1,000 children die as a result of diarrheal diseases from unsafe water and sanitation (6). Poor economics and infrastructure contribute to millions of people dying every year from diseases related to poor water and sanitation conditions. A study examining the impact of drinking water quality on child health in rural Ethiopia showed that uncontaminated household storage water decreased child diarrhea by 16% (8). Another major concern related to water quality is arsenic exposure which can cause an increased risk of cancers after prolonged ingestion (9). These statistics call for a greater urgency to be placed on clean drinking water as it significantly increases child health and is an essential step towards improving living standards. When sick children miss school, education suffers, economic opportunities are lost, and water-poor communities continue to be plagued with cyclical poverty. Safe water is also an essential resource for food production as many countries depend on agriculture as their main form of income; around 70% of all water extracted from rivers, lakes, and aquifers is used for irrigation (6). The quality of the water used for agriculture can affect the quality of crops and ultimately cause consumers to become ill. With water consumption related to agriculture expected to increase by 19% by the year 2050, it is increasingly important to ensure the quality of water for human consumption (10). Increasing access to clean water brings significant health, social, and economic gains. Inadequate water and sanitation is estimated to cause a 4.3% loss in sub-Saharan Africa's GDP and 6.4% loss in India's GDP as millions of people continue to die every year when improvements to infrastructure and management are not made (11).

How does the UN monitor and track the broad goal of access to water for all? The Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs) developed a global indicator framework to serve as a practical starting point for achieving these goals. Goal 6 is outlined into multiple targets covering universal access, water quality, resource management, and support for local communities. Although SDG

6 includes targets about water-use efficiency and sustainable water use, it does not seek to measure fair sharing of water. Few studies have given this particular research topic attention as it is a subjective topic and hard to measure quantitatively (12). Since the 1930s, international monitoring of drinking water and sanitation has been conducted, initially by the League of Nations Health Organization, then by WHO, and currently by WHO and UNICEF through their Joint Monitoring Program (JMP) (13). To narrow the scope, the majority of the research following relates to target 6.1: “By 2030, achieve universal and equitable access to safe and affordable drinking water for all” (14). Each of these words are carefully picked to craft an encompassing target.

Table 1. Language in Proposed Targets vs Normative Interpretation (15)

universal	Implies all exposures and settings including households, schools, health facilities, workplaces, etc
equitable	Implies progressive reduction and elimination of inequalities between population sub-groups
access	Implies sufficient water to meet domestic needs is reliably available close to home
safe and affordable	Safe drinking water is free from pathogens and elevated levels of toxic chemicals at all time and payment for services does not present a barrier to access or prevent people meeting other basic human needs
drinking water	Encompasses drinking, cooking, food preparation, and personal hygiene
for all	Suitable for use by men, women, girls and boys of all ages including people living with disabilities

Goal 6.1 is specifically measured by the indicator 6.1.1 “proportion of population using safely managed drinking water services” (16). A drinking water source is considered “safely managed” if it is an improved source located on the premises, free from contamination, and available when needed while “basic” drinking water services are defined as having an improved source that takes less than thirty minutes (round trip) to collect water from. The JMP developed the concept of “improved” water sources which has been used since 2000 to track progress towards sustainable access to safe drinking water, as called for in the Millennium Development Goals. As defined by the JMP, “improved” drinking water

sources, include piped water into user's plot, public taps, tube wells, protected dug wells/springs/rainwater collection (17). The SDG specifically identifies contamination by measuring *Esherichia coli (E. coli*), arsenic, and fluoride. The hope is that these technology types protect the user from outside contamination however previous research has indicated that "improved water" does not equal "clean water" (18). In moving beyond this definition of improved water sources, Indicator 6.1.1 is specifically designed to address not only the basic level of access but also safe management of drinking water services; accessibility, availability, and quality (19). The current data for availability and safety of drinking water is collected through household surveys and regulators. Even though a significant portion of people are without safe access, substantial progress has been made since 2000, as 1.8 billion people have gained access to basic drinking water (20).

There are currently a few different methods for collecting data and measuring the progress towards this goal. Household surveys and censuses, for instance, can provide high level information on types of water sources and if it is located on premises. Data collected through direct testing for fecal or chemical contamination in conjunction with data reported from administrative reporting bodies can provide a starting point for a regression line to estimate access to basic services for each country that the JMP produces. These estimates are reported separately for urban and rural areas and were used to report on "improved water" sources for MDG monitoring (19).

Beyond the high-level significance of research surrounding universal clean water access, it is also important to recognize biases that may come from data collection or commonly used definitions. A topic of particular interest to the following research is bottled water. Due to a lack of data on accessibility, availability, and quality, the JMP previously considered bottled water a source of improved drinking water if and only if another improved source is also used for cooking and personal (21). In most cases, those drinking bottled water also had access to piped water, allowing the JMP to redefine packaged and delivered water as improved (21). Discrepancies in data collection can exist as national statistics, regulators, and utilities all report information regarding availability, but do not use a consistent measurement technique. For global monitoring, the JMP focuses on "the amount of time when water is available" not necessarily the quantity of water delivered or quality in most cases (21). Only 34% of the global population have available estimates for water quality indicating that many developing countries may be noncompliant in providing data (21). There are currently a few different measures of availability; household surveys that are limited by varying questions and data from facilities which include generalizations about how many hours per day water must be provided in order to meet the global benchmarks. Both of these methods for measuring availability have limitations, making comparisons between countries and over time difficult. Many households often use multiple sources of water, yet national surveys and censuses usually only collect information about the main source of water which could provide inflated statistics if the main source is not available all year. Reporting accessibility is also important, as many households spend time and energy collecting water if it is not located on the premises, the responsibility mainly falling on women, providing motivation for improving access to safe water. Along with availability and accessibility, the JMP recognizes quality as an element of safely managed drinking water services, placing the highest priority on contamination from fecal matter which can be identified through detecting *E. coli*. Due to the variability of contamination, detrimental health effects can ensue from brief events that go undetected. Only a small proportion of countries have data on the amount of people using systems covered by a verified water safety plan, which the JMP recognizes as the most efficient way to ensure water safety (22).

Failing Water Infrastructure

There are many factors that contribute to lack of universal access to safe drinking water, including failing infrastructure from past development projects. Nonprofits and non-governmental organizations have been supporting the construction of water supply points and wells for many years. In a lot of cases, the wells ultimately become useless if they are not maintained or fixed when broken (23). A study completed in the Southern Region of Malawi showed that poorly functioning rural water supply points are most commonly attributed to poor water resource management and sub-standard borehole construction (24). Even though it is often assumed that water points fail due to poor operation, maintenance, or management, only 24% of the surveyed water points showed that this was the cause of the failure. The majority of the problems were as a result of poor construction of the boreholes before commissioning and are most often beyond repair (24). There are many reasons that projects focused on improving access to safe water can fail. These factors include poor planning or not understanding the community or country in which the project will be implemented (24).

In 2006, Tanzania launched a campaign to fix their water crisis and the World Bank joined their efforts in 2007. The World Bank provided Tanzania with financial and technical resources to support their plan to combine rural and urban water resource management. The campaign had received over $1.4 billion USD with the goal to bring improved water access to 65% of rural and 90% of urban Tanzania by 2010 until every citizen had safe drinking water. By 2012, only 53% of Tanzanians had access to improved water, a decrease from the access rate when the project began in 2007 (25). Reports found that communities were unable to raise the money to continue supporting the water sources like water points, wells, or water pumps contributing to this decline. According to Tanzania's water industry experts, the program is only intervening for a short time and is failing to address the fundamental challenges that result in their water crisis in the first place. By 2014, the program had brought access to 8 million people in rural areas, but the percentage of people with access to clean water decreased in Tanzania due to an increase in population (25). One factor that stood out in an investigative report for the *Ground Truth Project* and the *GlobalPost* was that the Water and Sanitation Development Project (WSDP) managers let communities decide what water systems they wanted to build. Since the project was left for the people to decide, when money was not a concern, communities wanted the most modern equipment they could get, regardless of how expensive it would be to maintain. Therefore, community's desire to have high-cost technology and the use of private contractors ultimately resulted in the project exceeding the budget and behind schedule (26).

World Vision, one of the leading humanitarian providers of clean drinking water in developing and emerging countries, has been working on water projects since the 1960s. They believe they can solve the global water crisis through developing vital water points and teaching local community members (27). A study by The Water Institute at the University of North Carolina studied water sources in Ghana and reported that almost 80% of the wells drilled by World Vision were functioning at high levels after 20 years, attributing the success to their community engagement model (28). But what about the communities whose wells are no longer functioning? Failing projects and infrastructure contribute significantly to the continued lack of clean water around the world.

Quality vs Quantity

Having universal access to safe water is not a new concern. It is important to acknowledge the difference between quality of water and quantity of water (scarcity). Even though it may seem that water access challenges are most obviously a challenge in the developing and emerging world, there are also significant access challenges in developed countries such as the United States. *An Overview of Clean Water Access Challenges in the United States,* a report published for the Environmental Finance Center to help identify challenges for the United States related to SDG 6, identifies six diverse access challenges. These challenges include contaminated wells, unsanitary wastewater disposal, lack of or substandard indoor plumbing, contaminated water supplies, or customers unable to pay water bills. Even though it is difficult to pinpoint a single reason for unequal access, it is important to recognize the different factors that could be at play in each country’s access to safe water. Some of the challenges are driven by the declining capacity of community water systems or individual household conditions (29).

There are currently multiple technologies used to purify water in developing countries with many new innovations on the rise. Boiling water, used in about 21% of households, is commonly used to disinfect drinking water as it kills most pathogens and parasites. The practice of boiling a daily supply of drinking water requires three times the fuel needed to cook daily meals and can lead to death from smoke inhalation. Many households also utilize Biosand Filters or Ceramic Water Filters. The Biosand Filters use granular media filters that are beds packed with sand and other materials to purify water while the Ceramic Water Filters use filtration technologies that treat water at the point-of-use. Water purification tablets, chlorination, UV treatments, and LifeStraws are additional methods for treating water (30). For many people, these techniques represent advancements that have been made for purifying their drinking water.

In many cases, a combination of different factors contributes to entire cities or countries living without universal access to safe water. In 2014 and 2015, São Paulo, Brazil faced a severe drought which pushed them towards a water crisis. The city's reservoirs were significantly reduced due to the combined effect of a stubborn government and the drought. According to Nate Millington, who investigated the state government of São Paulo's response, the water crisis can be attributed to inequalities in infrastructure as well as the inability to adapt (31). Sometimes, the lack of access to safe water is at no fault of the government, solely attributed to the lack of annual precipitation creating a water scarce country. South Africa has less than 500 mm of average annual precipitation and has uneven surface and groundwater distribution as a result of the climate and geography that contribute to their reduced quantity of water (32).

Water scarcity involves water stress, shortage, and crisis usually due to the combined effect of nature and humans including poor management, lack of government focus, and waste. India, a country with arguably the worst water crisis in history, faces this problem due to drought and failing to protect their water from overconsumption (33). India uses over 600 billion cubic meters, 245 billion being from aquifers, of water annually making them more dependent on water pumped from aquifers than any other nation. It is estimated that 80% of their residents depend on groundwater for drinking and irrigation (34). Projections estimate that by 2030, water demand will be twice the supply. If water users continually extract groundwater faster than it can naturally recharge, hundreds of millions of people will face severe water scarcity (35).

These few examples provide proof that a problem exists where quantity is concerned but overlook the fact that countries may have *enough* water but it may not be of drinkable quality. According to the WHO, there are currently at least 2 billion people globally that use a drinking water source contaminated with feces which can transmit diarrhea, cholera, dysentery, typhoid, and polio (7). Drinking water can become contaminated or polluted by means of inadequate management of wastewater from urban, industrial, and agricultural sources. Factors such as geographic, sociocultural, and economic inequalities further exacerbate the problems related to improved drinking water access and result in unsafe drinking water for billions of people (7). Many countries face public health concerns from exposure to arsenic in groundwater, an estimated 100 million people worldwide facing chronic exposure to arsenic through drinking water sources (36). Over one quarter of Bangladesh's population drinks water containing arsenic, making the country infamous for one of the largest public health crises in the world. Beginning in the 1970s, UNICEF started promoting the use of shallow, hand-pumped wells to stop countries from drinking dirty surface water, but the original testing of this water did not check for arsenic contamination. In most cases, digging wells deeper than 500 feet will eliminate this concern (37). The first step towards making progress towards universal access to safe water is identifying if the root cause is related to quality or quantity. Many communities struggle to manage resources properly to have enough quantity of water while other communities struggle to have water of drinkable quality. Environmental factors combined with poorly managed resources leave millions of people without this essential human right.

Cost of Water

Beyond an influx in capital for investments to translate to increases in service, finances and institutions will need to be strengthened. According to a World Bank study, *The Cost of Meeting the 2030 Sustainable Development Goal Targets on Drinking Water, Sanitation, and Hygiene, "*current levels of financing can cover the capital costs of achieving universal basic service for drinking water, sanitation, and hygiene by 2030, provided resources are targeted to the needs" but the SDG water and sanitation goals cover more than basic services and the "capital investments required to achieve the water supply, sanitation, and hygiene SDGs amount to about three times the current investment levels" (38). It is also important to understand that capital costs reflect the immediate financing needs but do not take the operation and maintenance costs into consideration which by 2030 will exceed the annual capital cost requirements to meet the remaining unserved (38). The World Bank, UNICEF, and WHO estimate that $28.4 billion per year from 2015 to 2030 would be needed to extend basic water and sanitation services to those currently without (8). Often times, people in developing countries are spending significant portions of their income on water that is not safe to drink. For example, in Papua New Guinea, 54% of a typical low-income person's salary is spent on the 50 liters of water that WHO recommends as a minimum to meet basic daily needs (39). People are forced to make the impossible choice each day; to cut back on water use or collect potentially dirty water.

Progress Achieving the SDGs

The JMP reported that the MDG target for improved drinking water was met five years ahead of schedule, in 2010, and that 90% of the world had access to improved sources (40). Amongst this seemingly ambitious reporting, many critics disagreed with this assessment, citing the definitions chosen, missing data, measurement strategies, and uneven progress across regions. The JMP data did not account for water quality, which ultimately led their statistics to being misrepresentative of estimates for safe water access. For example, in 2005 the JMP estimated that 77% of people in urban areas of Tanzania had safe drinking water but national data reported only 40% (13). By not researching the quality of water and only relying on household judgements about whether their water was drinkable, the MDG success rate is lower than originally reported (41). The many limitations that exist when trying to quantify statistics for progress on the SDGs call researchers to place a greater emphasis on eliminating as much bias as possible. Human error is inevitably introduced, yet we can focus our efforts on collecting data in the most representative way possible. By narrowing the scope of this research to a gap identified, bottled water, we can get a better picture of the reality for many people in emerging and developing countries. The broadening of definitions and inclusion of particular water sources in improved versus unimproved show the progress that has been made in recent years to meet the ambitious targets. WHO reports that 90% of the global population uses at least a basic service (7). As far as progress on SDG 6, according to the UN-Water SDG 6 Data Portal that was launched in August of 2019, 71% of the world's population is using a safely managed drinking water service (42) meaning that 785 million people still lack even a basic drinking water service (14).

SDG 6 has been expanded upon since the end of its closely related MDG Target 7.C which was to halve the proportion of the population without sustainable access to safe drinking water and basic sanitation by 2015. SDG 6 emphasizes integrating water and sanitation while improving sustainability which is an improvement from the MDGS, which were more separate goals and did not encapsulate a holistic approach. Even though global indicators exist to track progress, individual countries are tasked with creating national targets as each country has unique circumstances limiting their access. Improvements can also be seen through revised definitions for desirable outcomes as far as water and sanitation. For example, the wordage "safely managed" from the SDGs, comparable to the MDGs "improved drinking water source," is more representative of the highest level of water access along the spectrum. Since the JMP has begun coordinating with national regulatory agencies and local service providers for data, the local conditions will be more accurately represented through reported data (41).

These adaptations from the MDGs demonstrate improvements and progress that have been made in recent years. Despite all of these new tactics for progressing safely managed drinking water, there are still many challenges that remain for communities and policy makers.

Challenges Remaining

With changing weather conditions and rising temperatures, projected worldwide availability of water remains a challenge. Climate change affects the distribution of rainfall, snowmelt, river flows, groundwater, and water quality (43). New technologies and investments that may be required for the changing climate are out of reach for many low-income cities. Among the already present challenges for engineers and policy makers, rising global temperatures and climate change threaten to exacerbate dry spells and dangerous floods leading to intense water shortages. Shortages of water can reduce flows in rivers, leading to increased levels of harmful pollutants as well as increase the risk of wildfires as a result of droughts (44). Increased flooding threatens to stunt progress on SDG 6 as it can destroy water points and contaminate water sources while droughts further intensify water scarcity. Climate change significantly impacts the water cycle through increased precipitation intensity, receding glaciers, and longer dry periods. Many cities rely on coastal aquifers which can become contaminated with salt as sea levels continue to rise. Coastal cities are forced to plan strategies to adapt with the prospects of rising sea level by building seawalls, planting vegetation to absorb water, and redesigning roads (45).

Scope of Research

The literature review presented in Chapter 1 provides an outline for understanding the complex issues surrounding safe water access for the world. It touched on the SDGs, global engineering challenges, the progress that has been made towards safe water for all, and the goals that the UN has laid out for the future. Goal 6, Target 1 regarding achieving universal and equitable access to safe and affordable drinking water was narrowed in on to focus the remaining of the analysis. Because the factors that contribute towards lack of quality or quantity of water vary between cities, countries, as well as by urban or rural settings, this paper will investigate the Mekong Delta of Vietnam (Chapter 2) and Western Kenya (Chapter 3) as case studies. After investigating Vietnam and Kenya in great detail, scientific conclusions (Chapter 4) and personal reflections (Chapter 5) will be presented.

Chapter 2

Case Study: Vietnam Mekong Delta (VMD) Region

To accomplish universal, safe, affordable drinking water for all by 2030, it will require countries to put a strong emphasis on their water resource management. A country whose water resources has been an integral part of the economy, government, and identity is Vietnam. Vietnam has given expansion of irrigation and drainage and water resources development top priority in recent decades (46). Water is extremely important to communities in Vietnam as almost two-thirds of the population lives along the three main river basins (Thai Binh, Mekong Delta, and Dong Nai), the largest being the Mekong Delta which will be the focus of this case study. Even though Vietnam has vast rivers flowing through the country, the lack of physical infrastructure and financial capacity means the abundant supply of water is not always utilized to its full potential. Paired with the uneven distribution of water due to variation of rainy seasons as well as upstream water diversion projects, there can be water shortages throughout the country (47). In order to continue tackling the country's water crisis, Vietnam issued regulations in 2008 to all urban water companies to implement water safety plans. In 2012 it became mandatory for all water suppliers to implement water safety plans that eliminate contamination of source water, treat it, and prevent recontamination during storage and distribution. The Ministry of Agriculture and Rural Development has also been promoting household water treatment and storage in communities without protected water sources. As of 2015 only 61% of urban households and 10% of rural households received piped water (48). In terms of biodiversity, the Mekong River system is the world's second richest river basin. Farmers in the Mekong Basin produce enough rice to feed around 300 million people every year as its floodwaters deposit fertile sediments on fields and wetlands. The Mekong Delta is significant to Vietnamese culture as much potential for agriculture and aquaculture production exists, with 4 million hectares of cultivable land for 18 million residents (49). The Mekong Delta is extremely important for the prosperity of Vietnam, yet many factors inhibit productivity and sustainable development for the region.

The threats to Vietnam's water resources can be categorized into environmental issues and governance challenges, which will subsequently be described in order to detail the many factors at play.

Threats to Vietnam's Water Resources: Environmental and Political

With the majority of the population living along river basins, much of the land in Vietnam is susceptible to flooding. Estimates articulate that about 70% of the total population is at risk of water related disasters (50). The Mekong River Delta is prone to flooding from monsoon rains as well as typhoon storms (50). A study of flood hazard maps in the VMD determined that the flood hazard area is 97.6%, with 57.3% of the total area within high and very high hazard zones (51). Flood risk maps prove that there is hazard and risk associated with living and farming in the VMD which presents safety and economic concerns as the economy is heavily dependent on the coastal lands for water-rice agriculture. Poor maintenance in conjunction with inadequate infrastructure significantly impacts the economy, currently estimated as a 1.5% GDP loss per year (52). Climate change also exacerbates disasters stemming from poor management and land-use changes (52). Sea level rise, as a result of climate change, causes seawater to be pushed upriver and cause saltwater intrusions. More effects of climate change include increased total annual runoff, more rain in wet seasons while less rain in the dry seasons, meaning less predictability and more extreme events (52).

Pollution, mainly from urban and industrial wastewater, is currently one of the greatest water-related threat to the economy (52). Agriculture is also a source of water pollution as fertilizers, pathogens, and pharmaceuticals fed to animals generate waste (52). The cost surrounding water pollution is quite high, resulting in underinvestment and relaxed enforcements of regulations. WHO's organic pollution standards for drinking water are currently not met in any of the surface water coming from river basins (52). Untreated wastewater is discharged directly to the environment and it was estimated that operating industrial zones with wastewater treatment plants were only treating 71% of the wastewater produced in the zone. Many industrial factories located outside of industrial zones, hospitals, and private clinics do not have wastewater treatment facilities. The regulations surrounding wastewater management require all businesses and service establishments to be connected to treatment plants in their industrial zones, yet many businesses are exempt from this requirement, contributing to the challenges surrounding enforcing these regulations. For some agencies, it is easier to the pay the fee associated with wastewater discharges rather than investing in a cleaner environment (52).

Due to the geographic location of Vietnam, the Mekong Delta is susceptible to water resource decisions made in the upstream countries; China, Myanmar, Thailand, Laos, and Cambodia. The upper Mekong River in China is controlled by dams and reservoirs that alter navigation patterns and flow to the Mekong Delta. The first of many dams planned on the lower Mekong has been constructed in Laos and has been highly contested by environmentalists, Cambodians, and Vietnamese (53). If all of the proposed dams are built, more than half of the lower Mekong River water would be captured in reservoirs, significantly affecting the flow of the river. Not only will the reservoirs capture water, but they will also trap crucial nutrient-rich sediments that are relied upon to fertilize fields in the Mekong Delta and feed fish (53). The Mekong River Commission (MRC) reported, in July 2019, that water levels had fallen to the lowest on record as a result of unseasonably low rainfall, maintenance work on the Jinghong hydropower station in China, and testing of the Xayaburi dam in Laos (54). The MRC is an inter-governmental organization that works to collectively manage the shared water resources and development of the Mekong River. Although there are six countries with land in the Mekong River Basin, the MRC only has formal participation from the governments of Cambodia, Laos, Thailand, and Vietnam.

Drinking Water in Vietnam

According to 2017 data from the WHO/UNICEF Joint Monitoring Program (JMP), 94.7% of Vietnam's population had access to "at least basic" drinking water while 5.3%, around 5 million people, have “unimproved” drinking water (55). While a significant percentage of the population has access to improved drinking water sources within a 30-minute roundtrip, a number of people are still drinking water from unprotected wells or springs. Services for piped water have been greatly expanding in recent years, and even as of 2015, 61% of urban households and 10% of rural households had access to piped water (48). The exploitation and pollution of Vietnam’s rivers has limited people’s access to clean drinking water. Water resources in the basins of Vietnam’s major rivers have been degraded due to excessive exploitation, the majority being for agricultural use and energy production (56). Areas with depleted rives and lakes are then more susceptible to pollution from farming pesticides, fertilizers, and wastewater resulting in people in Vietnam’s rural areas lacking daily access to clean water (56).

Many people that are not connected to piped water choose to buy their water, either from tankers or bottles. Even people that do have piped water on the premises often choose to boil the water as they are skeptical of the quality. Communities in the Mekong Delta consider the quality of their water of utmost importance and are familiar with the health benefits of drinking clean water. A recent trend in Vietnamese households is to purchase the equipment necessary for treating water and make a business of bottling and selling this clean water. With households finding it necessary to invest in the technology to make this a reality for themselves, the question remains how much better is this water than the piped water on their premises?

Methodology

Since the Mekong Delta’s water resources are susceptible to the environmental and political threats, it is a relevant place of study for the impacts on the quality of water. The remaining discussion in this case study will be focused on exploratory research conducted in the Mekong Delta region of Southern Vietnam in August 2019 to learn more about the water quality and management. Through a partnership with An Giang University and approval from the Department of Food Safety, we were able to travel to six different household or factory plastic water bottling plants to collect qualitative and quantitative data in the An Giang Province. The government has been installing piped water in homes for a number of years leading to increased access to improved drinking water however many people do not trust this water enough to drink it though they do use the water for daily household uses. The piped water is typically treated with chlorine, often leaving a chlorine-like taste in the water, which people either do not like the taste of or assume the water is contaminated. Therefore, many households still seek to purchase bottled water or household water treatment technologies for their home drinking needs. This has created an opportunity for local entrepreneurs to invest in bottled water treatment technology, often by means of taking loans from family or friends, to purify and bottle the water themselves in their home for personal use and to sell. We were interested in the water management as well as the quality of the water produced in the home.

Site Description

To begin, in the Tinh Bien district, we traveled to three sites, AST, Hoang Tien, and Seven Mountains. The Tinh Bien district's geography consists of upland and mountainous areas. On average, the work experience of the local business was three to five years with the exception of the largest factory that has been in operation for ten years. The first plant in Tinh Bien, AST, has been in operation for three years and uses water from wells and pipes before filtering. During the dry season, it is common for the well water to not be available here. In this specific community, residents would frequently drink the rain water before the bottles were available as they considered the piped water untrustworthy. The second site, Hoang Tien, used only piped water and was unable to provide more qualitative information as only one employee was present. Lastly, we visited Seven Mountains that filters all of their water from an 80-100 meter well located on the premises that was reported to be available year-round due to the depth and geography of the specific area. The next day, in Chau Phu district, which has a floodplain topography, the first site, Cali, was an operation that took place in a woman's home as a result of borrowed money from her family. She employs her family members and her husband was in the process of getting a license to allow him to drive the truck so they no longer have to outsource this part of the business. All three household plants, Cali, An An, and Mibi, used piped water that was available throughout the entire year. Every site that we visited reported not much help from the local government in terms of running their business. But they are subject to quality checks for the water every six months. All of the employees reported wanting to produce high quality water for their neighbors and community. A map of the districts worked in can be seen below in Figure 1.

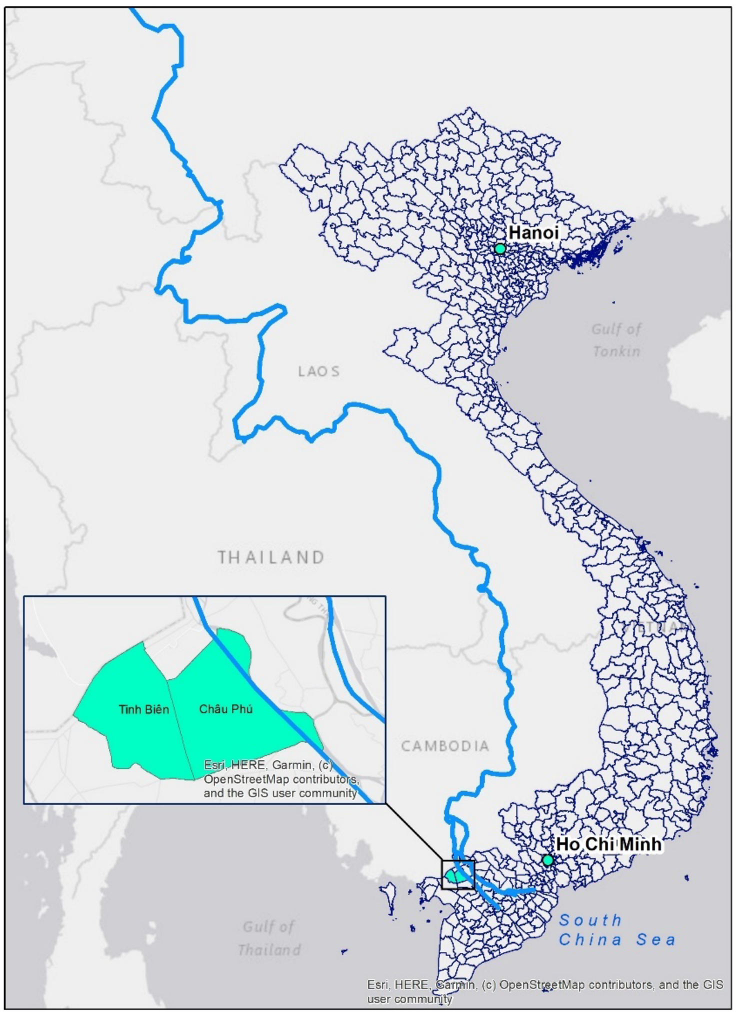

Figure 1. Map of Vietnam and Districts

As referenced earlier, the JMP places emphasis on determining if water is contaminated by fecal matter which can be suggested by the presence coliform bacteria, indicator organisms comprised of many different species of bacteria, including fecal and non-fecal coliform bacteria. Naturally found in the intestines of warm-blooded animals, many fecal coliforms cause diseases and their presence can indicate contaminated water. One of the most common species of fecal coliform bacteria is *Escherichia coli, E. coli*. Past studies surrounding the Mekong Delta region have indicated high or very high risk levels of *E. coli* present in 67% of samples from improved sources (18). Due to this prior knowledge of potential contamination from *E. coli* in the water, we were specifically interested in testing piped water sources and bottled water sources for *E. coli*. Aquagenx has created a simple on-site water quality testing using color-match scoring to determine the Most Probable Number (MPN) of *E. coli* in a 100 mL sample called the Compartment Bag Test (CBT). The CBT uses a growth medium that turns blue when metabolized by *E. coli*, indicating contamination (57). The CBT follows WHO Guidelines for Drinking Water Quality, which evaluates the health risk based on the presence per 100 mL of water (Table 2).

Table 2. Risk Level Associated with *E. coli* Classification (57)

WHO Classification	***E. coli* MPN/100 mL**
Low Risk, no action required	<1
Intermediate risk, low action priority	1-10
High risk, higher action priority	11-100
Very high risk, urgent action required	>100

The government allowed us to visit these specific household and small factory bottling plants, only under the supervision of a representative from the Ministry of Agriculture and Rural Development. At each site, water samples were collected from the filtered water sources and the unfiltered piped or well water, whichever was available. 100 mL samples from each source were collected in Stand-Up Whirl-Pak Thio Bags which contain a white tablet of sodium thiosulfate to neutralize residual chlorine in the sample. In order to prevent cross contamination, plastic gloves were worn and the inside of the bag was not touched. Upon completion of sample collection, Aquagenx EC+TC growth medium is dissolved in the samples and the sample will turn yellow/yellow-brown as seen in Figure 2.

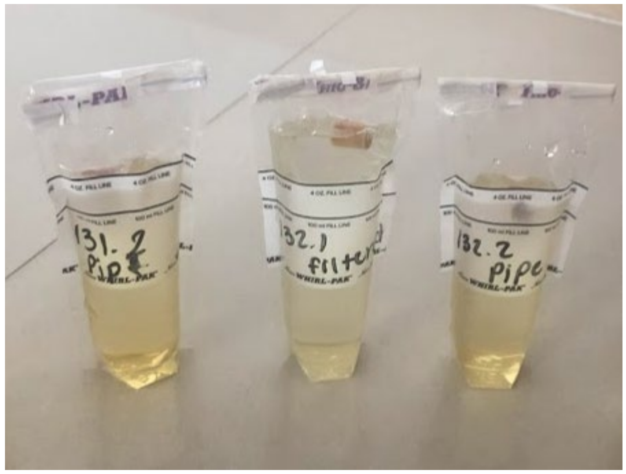

Figure 2. Example of Whirl-Pack Thio-Bag with Dissolved Growth Medium

Once the entire growth medium is dissolved, the sample is then poured from the Thio-Bag to the Compartment Bag which contains five compartments of varying volume in order to statistically compute the MPN of *E. coli* after the 40-48 hours of incubation required since the samples were kept outside. After the incubation period, certain compartments may have turned blue/green, indicating a presence of *E. coli*. There are 32 different results that can ensue from combinations of blue and yellow in the respective compartments. Aquagenx has developed an MPN table from each possible iteration of blue and yellow. For example, if each compartment is yellow, the most probably number of *E. coli*/100 mL is zero meaning the WHO Health Risk Category is low risk/safe. Example CBT's can be seen in Figure 3, with three low risk/safe examples and one very high risk bag.

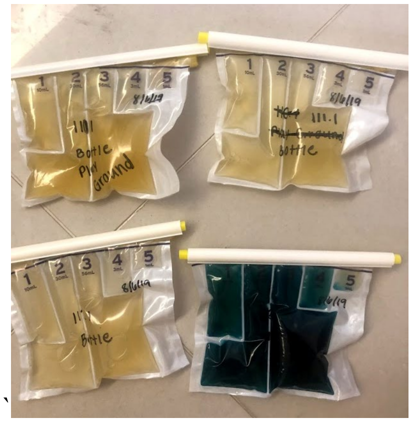

Figure 3. Example Compartment Bag Test after Incubation

Results

After the proper incubation period in the Compartment Bag Test, the following results were obtained from the samples taken. Figure 4 represents the percent of prefiltered and filtered samples from the Tinh Bien and Chau Phu districts that were resulted in Low or High Risk regarding presence of *E. coli*.

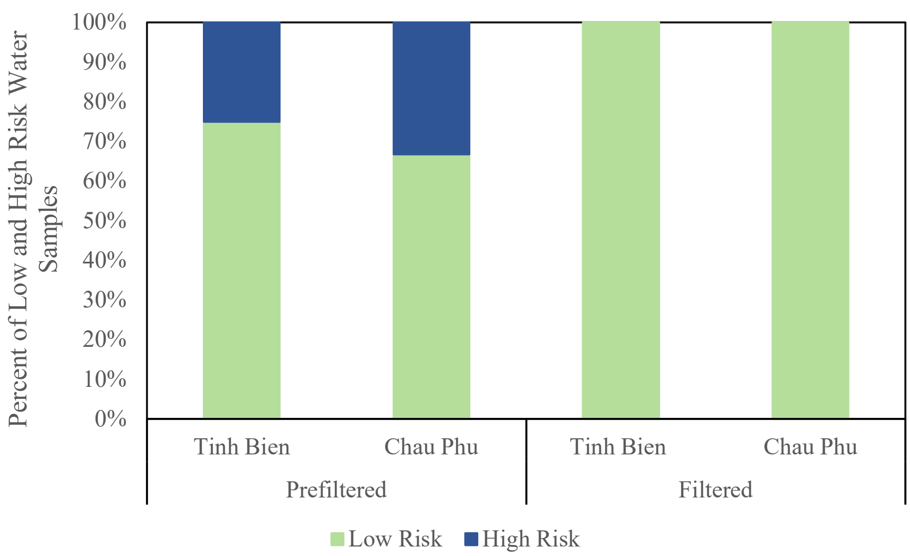

Figure 4. Percent of Low and High Risk Water Samples

Throughout this process, it was observed that many household plants purchased the equipment necessary for plastic bottling. The only sources at plastic bottling plants that contained *E. coli* based on the initial exploratory research were from piped water sources located on the premises. Each plant had their own unique process for cleaning, filling, labeling, packaging, and delivering the bottles. As well, the bottles were all sold for relatively similar prices (around 25 – 50 cents). There are many potential sources of contamination for the water, including storage containers or the bottles not being cleaned thoroughly enough. When we collected water samples, we collected directly from the source that would be filling the bottles, like the spout seen in Figure 5 from the Tinh Bien plant.

Figure 5. Tinh Bien – Filling 20 Liter Bottle with Filtered Water

The plants along with having their own unique method for the process, had similar water filtering technology, much like the set up shown in Figure 6 at Waves. At every site, we tried to determine the technology used for filtering, but we were mainly just informed about when and where the equipment was purchased.

Figure 6. Water Filtering Technology at Waves

One of the larger plants, Seven Mountains as shown in Figure 7, had a completely automated conveyer belt system that would clean, cap, label, and date every bottle. The owners of Seven Mountains opt to send water samples to Ho Chi Minh City every few months in order to ensure the quality of the water they are producing. This is an optional testing, but a true testament to the worker's accountability to provide clean water.

Figure 7. Seven Mountains Conveyer Belt

Cali, as shown in Figure 8, was started in 2015 by a woman that pursued the plastic water bottling business for her and her family because she did not trust the bottled water that she had access to in her community. The majority of the local people surrounding her home drink the water that she sells and before she began her business they all drank the piped water. She told us the hardest part of the business is cleaning the 20 liter bottles. When she began her business, the Deparment of Food Safety instructed her on how to properly clean the bottles, filter the water, and measure the pH with a device she bought. Since then, the government has not assisted her at all.

Figure 8. Cali filtering and bottling facility

A husband and wife in Chau Phu have carried on the bottle business An An after their son started the company, thinking it was a good market to invest in. Since beginning in 2016, more competitors have entered the market, meaning they only produce about twenty 20 liter bottles each day. Pictured in Figure 9 is the business owner, cleaning the bottles by hand.

Figure 9. Vietnamese Woman Cleans 20L Bottles at An An

The last site in Chau Phu, Mibi, as seen in Figure 10, was started by a woman who wanted to produce high quality water to contribute to her community. Most of the people in the surrounding area buy water from her. Before she was in the bottling business, she worked for an agriculture factory.

Figure 10. Filtering Technology at Mibi

Throughout meeting and talking with local community members that are producing water for their communities, it is evident that people take their health and water very seriously. The Vietnamese place an emphasis on health through drinking clean water. We learned people start the businesses with the intentions of contributing positively to their community. All of these plants, with the exception of Seven Mountains, have been under operation for less than four years.

Before we had received authorization from the government to travel to test water at the households, we visited a few sites without actually testing. One of the households, Fresh Water as seen in Figure 11, had open storage containers that could have been a potential source of contamination. The owner was not present, so we did not receive any additional information about their specific practices.

Figure 11. Fresh Water

We also had the opportunity to visit the largest factory in the region, Water World, that sells one thousand 20-liter bottles per day. The company filters the water using Reverse Osmosis and UV technology as shown in Figure 12. Water World, like many of the other companies, offers customers incentives for returning the 20-liter bottles after use. Once the bottles are returned, they are cleaned with piped water and placed in the sun for two days, and then rinsed again with drinking water. They keep reusing the same plastic bottles until broken.

Figure 12. Reverse Osmosis System at Water World

Discussion

Along with testing water at the official household plants, we also had the opportunity to talk with families about their views on bottled and piped water in their communities. The overall takeaways we learned from talking with residents can be summarized in the following three points; people are extremely health conscious and care about the quality of the water they are drinking, people are willing to invest in technology to filter water for their families because they have found a market, and the local perception is that the government does not assist in providing clean water. One household in particular was owned by a woman who found it extremely important to have clean water for her guests and grandchildren. She would transfer water from the 20-liter bottles to smaller bottles to be placed in sun for an entire day, then run the water through a ceramic filter before drinking. The ceramic filter used in this household can be seen below in Figure 13. She was pleased with this method as she does not trust the piped water for drinking. At this location, an intermediate risk according to the WHO Health Risk was found from the water that was being kept in the sun. The water that was tested from the filter proved to be low risk or safe (data not shown).

Figure 13. Ceramic Filter

We saw a common trend between people not trusting piped or river water and switching their drinking water to a bottled source. Depending on the size of the family, people can spend around $1 – 2.50 USD per month on bottled water.

Conclusions

We arrived in the Mekong Delta region with a hypothesis that some of the "improved" water sources may contain *E. coli* as past research in the region has indicated many protected water sources are actually contaminated. Since the trend of household plastic bottling plants is relatively new and generally trusted by communities, we were curious to see if these "improved" sources were contaminated with *E. coli*. Following our field collection, we had the opportunity to meet with Romain Joly, the Managing Director of 1001fontaines, an NGO that works to purify water in Cambodia, Madagascar, and Vietnam. Through his experience working to provide clean water, he believes that there is much need to further investigate the quality of the water being produced from the household plants. Based on his company's testing, he believes that a substantial portion of the bottled water in Vietnam contains *E. coli*. His NGO is working to partner with local community members in order to provide a system they believe produces safer water to drink. After spending two weeks investigating this topic through exploratory research, we determined that of the six plants we tested, none had a presence of *E. coli* in the filtered water being bottled and sold. There are many more plants in the surrounding region, although from our investigation, there may not necessarily be a need to conduct an in-depth study of the factories in the area.

Chapter 3

Case Study: Western Kenya

The water and sanitation crisis in Kenya remains critical, as 41% of the population still relies on unimproved water sources and only 9 out of 55 public water service providers offer continuous water supply (58). As with most countries, the water challenges cannot be attributed to one factor, but many complexities working together. In Kenya, providing water at the household level is primarily a responsibility for women and young girls. Depending on how far the water source is, collecting water could take many hours a day (59). Due to the lack of infrastructure and scarcity of water that is present in Kenya time spent traveling to obtain water could take up a significant portion of the day. World Vision reports that in sub-Saharan Africa, women and children average walking 3.7 miles each day to collect water (60). Many women are frequently confronted with violence and intimidation at public water sources (61). Women in Kenya are responsible for providing water, but are less likely to have safe access to water compared to men (62). In one scenario in Marsabit county, women served their leaders dirty water in order to protest the community not placing a strong enough emphasis on increasing access to clean water (62). Most Water Management Committees in Kenya are registered under county governments. County governments require one third of the members are required to be women, resulting in many women being given "token membership" where their input and contributions does not influence any decisions (59). In order to increase women's contribution to water resource management, social norms and the culture should adapt to be more inclusive of women.

Beyond societal issues surrounding water in Kenya, there are also negative impacts associated with climate change and long periods of droughts. Kenya is considered a water-scarce country as their volume available per capita is below the international benchmark due to drought cycles and lack of rainfall (63). Droughts have dried water bodies while lowering the water table and precipitation patterns are affected by deforestation and overgrazing (63). Beyond droughts, a natural shortage of water is already present due to arid and semiarid lands making up the vast majority of the total land area in Kenya (63). These environmental, social, and political factors work in conjunction with each other, creating a unique critical water situation for Kenya.

Methodology

Aqua Clara Kenya (ACK) is a nonprofit that has constructed, installed, and sold over 7,000 water purifiers since their establishment in 2007 (64). ACK focuses on the belief that projects should be locally managed and driven through the training of local experts to build products from locally sourced materials. This process helps to create more small businesses that are sustainable as they are run by locals (64). During the summer of 2019, ACK conducted household surveys across three counties to determine their progress in accordance with the Sustainable Development Goals. Lauren Trepanier, a PhD student in the Water Resources Engineering Program at Penn State and researcher for the Food-Energy-Water Systems Laboratory, collected water quality data as part of ACK's evaluation. Seven water quality samples were taken at each site, four surrounding biological contamination and three surrounding chemical contamination. The biological contamination was evaluated in 344 samples by taking water samples directly before entering the filter, tap on the filter, a cup filled with water from the filter, and an alternative storage location within the home. Lauren was responsible for conducting Compartment Bag Tests, using the same process as in Vietnam (see Chapter 2) in order to test for *E. coli* in each of these samples. Chemical contamination was evaluated in 258 samples by testing for Fluoride through an ExTECH FL600 Fluoride Meter and Arsenic through Industrial Test Systems Inc. Arsenic Econo-Quick Assessment System. Fluoride and Arsenic were tested on samples that were taken before filtering, from the tap of the filter, and an alternative storage location. The water was sampled from 86 sample sites from filters sold to households in three different counties. ACK directed household sampling decisions. The three counties were specifically Kisii, a periurban area, Nyamira, an agriculturally rural area, and Narok, a seminomadic rural area. Nyamira and Narok were in part chosen due to their participation in a health club, Washiriki, that had led these counties to begin health clubs of their own within the last year.

Results

The remainder of this case study will focus specifically on results pertaining to responses in the household information concerning access to water sources and the presence of contamination in the samples. Due to the variations in geography surrounding the sampled sites in Kenya, reported levels of access varied significantly. An important factor to consider when discussing universal access to water is the minutes required to collect water each day. Figure 14 shows the juxtaposition of minutes required to collect water for each county during the dry and rainy season. The average, maximum, minimum, and most frequently reported values are shown.

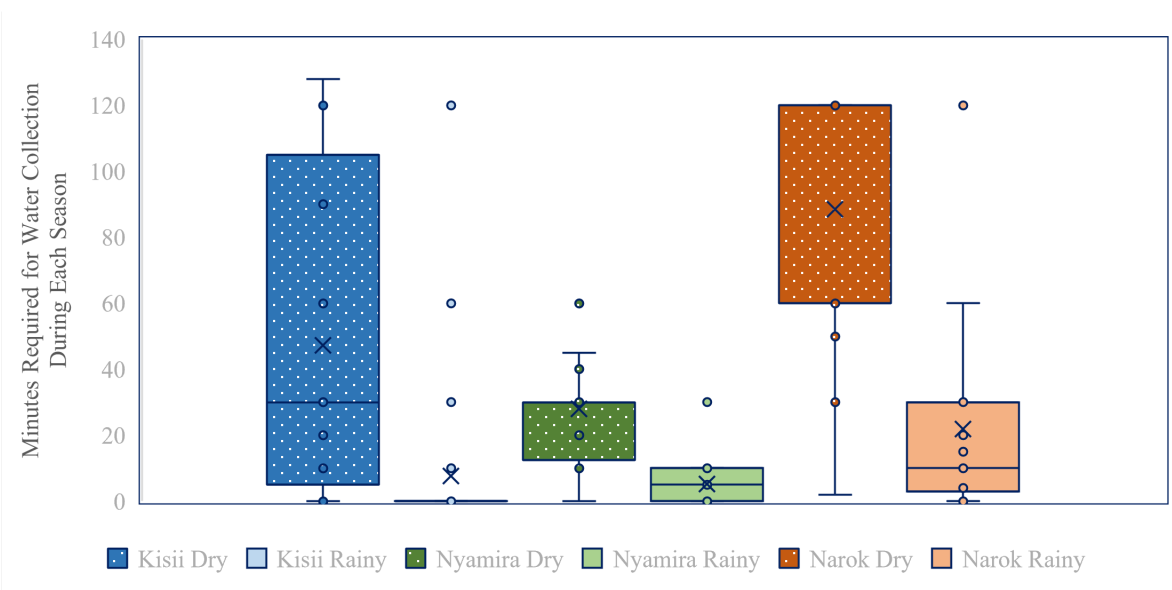

Figure 14. Minutes Required for Water Collection During Each Season

During the rainy season, average time to collect water decreases, yet some people reported values as high as 120 minutes. The average time required for water collection in Nyamira during both seasons is lower than in Narok or Kisii. During the dry season, the average reported times for Nyamira, Narok, and Kisii were 28, 88, and 47 minutes and during the rainy season 5, 22, and 8 minutes respectively. It can be seen through these results that the time to collect water significantly reduces during the rainy season.

When testing the biological contamination of sources in each county, four different samples were taken at each site. Water was tested directly from the source, the tap after being filtered, a cup that was filled with water from the tap, and a storage container elsewhere in the home. The following figure represent the number of samples in each county that correspond with certain risk levels.

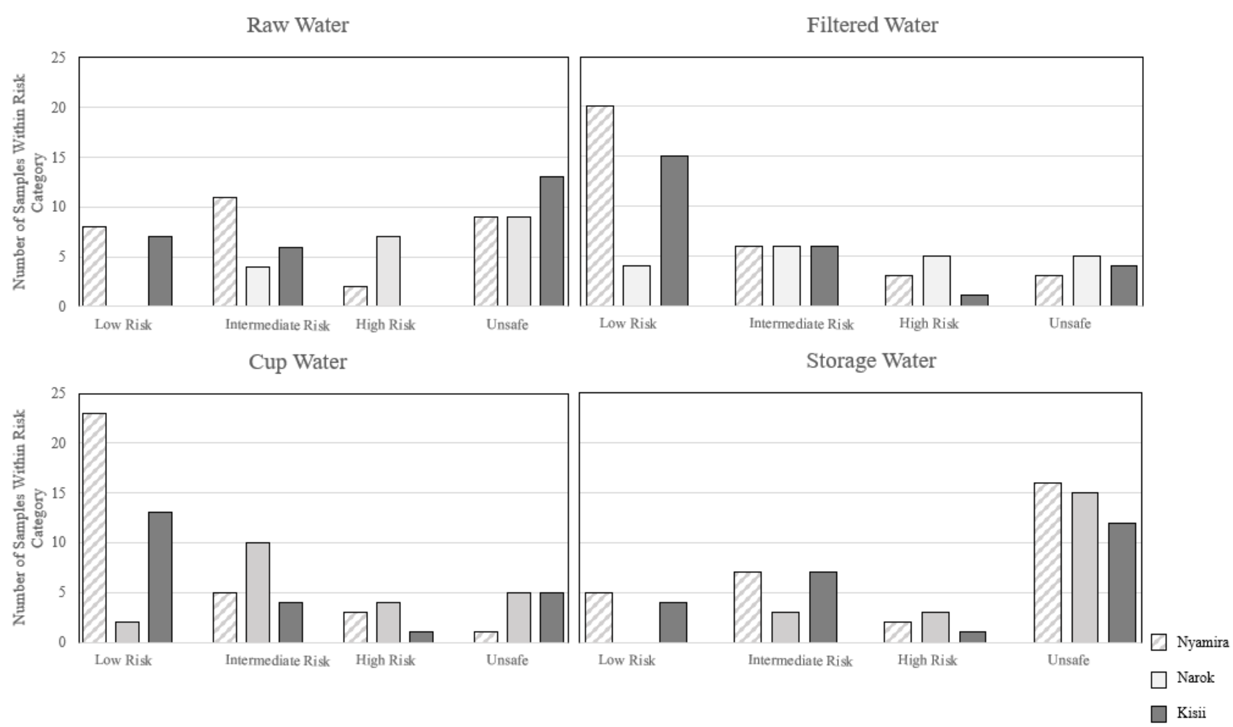

Figure 15. Number of Samples with Varying Risk Factors

In general, the filtered and cup water samples reported the lowest risk, although there was still a significant number of reported samples that had higher risk levels. Unsurprisingly, the raw water samples in each county were generally unsafe. In each county, about a third of the samples from the storage containers reported unsafe levels of *E. coli*. Each county varied in regard to the percent of sample sites that achieved certain service levels according to the SDG definitions. The values reported for at least basic service levels were 88% of the 32 samples sites in Nyamira, 8% of 25 samples in Narok, and 72% of the 29 sites in Kisii. The varying levels of service associated with the three counties can be attributed to the varying levels of infrastructure and development that exists.

Discussion

Kenya, and sub-Saharan Africa in general, are behind in terms of accomplishing the Sustainable Development Goals (65). Through the information ACK collected, it can be seen that the average time required decreases in the rainy season. The households also reported their main source of water in each season, which frequently changes from springs to rain water collection from the dry to rainy season. When comparing the reported risk levels of *E. coli* from filtered water samples to that we found in Vietnam, it is evident that there was much more biological contamination in Kenya. This result of more contamination in Kenya could be due to a variety of factors. Specially, the filters tested in Kenya were in plastic storage containers that frequently need to be cleaned. If communities do not have access to clean water, there is no possible way to safely clean the inside of the storage container. Even if the filter is working properly, if the storage container is not free from contamination the water can be unsafe to drink. Much of the contamination in the filtered samples is most likely due to cross contamination from hands, animals, or insects. Filters are complex, meaning it is difficult for them to behave properly at all times. The rural counties in Kenya that were selected for this study were less densely populated than the rural sites in Vietnam. In Vietnam, the factories that we tested were required to send samples to be tested every few months. This increased need to keep water quality up to specific standards could have contributed to the factories in Vietnam having no *E. coli* in the samples we tested. As well, the lack of infrastructure in

Kenya contributes to the differing results. In Vietnam, the government had begun installing piped water to reach rural communities. This infrastructure is not prevalent rural or semi-rural in Kenya, leading people to use more surface or rain water as their main source of water. In Vietnam, most of the water sources that were being filtered originally came from piped water that did not have significant levels of *E. coli* from our testing. In Kenya, the original sources of water ranged from unprotected dug wells, springs, rain water, surface water, or water pans. These sources of water that may have more contamination to begin with could result in the filters being overworked, reducing its life span. The source of water could potentially impact the effectiveness of the filter. Some community members in Kenya reported that water issues can be as a result or people's respect for their ancestors. When a respected member of a family or community has passed down water management techniques for many generations, people question why a change is necessary. This reverence for the past has resulted in many generations of people being too set in their current ways to change how they manage their water. The many social, political, and environmental differences that exist when comparing Kenya and Vietnam could be cited as the cause of the differing results in these studies.

Conclusions

The results in Vietnam and Kenya surrounding *E. coli* contamination in filtered water samples were vastly different. For samples in Vietnam, we found no unsafe samples that had been filtered. In Kenya, there were significant levels of *E. coli* in some filtered water samples and many storage container samples. These varying results can be attributed to differences in cleaning procedures, infrastructure present, and filtration technology. There are potential limitations involved in the study as ACK provided the sites that the team was able to take samples from. The three counties in Kenya that were analyzed in this study showed variation between levels of access. The least developed county, Narok, had a large proportion of people using surface water, contributing to their low levels of at least basic service. There are potential future research topics that this study gained some insight into. For example, correlations can be seen between presence of *E. coli* in the filtered sample and the original source of water. This study did not represent enough data on different source types therefore specific conclusions cannot be drawn regarding this research question at this time. A future research topic could include increasing the number of samples taken from various water source types.

Chapter 4

Scientific Conclusions

The 17 Sustainable Development Goals that UN Member States are working to achieve by 2030 provide a baseline for all countries to strive towards peace and prosperity for people and the planet. The goals range from health, education, equality, and ending poverty. Although all of the goals are crucial to obtain, the one analyzed frequently in the Civil and Environmental Engineering realm is Goal 6, which ensures access to water and sanitation for all. Unsafe water, sanitation, and hygiene lead to millions of deaths every year. Having safe access to water is one of the most basic human rights that is not easily achieved in many developing and emerging countries. Engineers and policy makers are tasked with developing innovative solutions to these global problems in order to accomplish the SDGs. Climate change has contributed to many countries falling behind the targets. In order to investigate the current state of water access in Vietnam and Kenya, studies in each country have been analyzed.

In Vietnam (Chapter 2), we traveled for two weeks to study the water quality of small household level plastic bottling factories. In order to investigate the quality of water, we did exploratory research to obtain a better understanding of the current state of bottled water quality. We used Compartment Bag Tests to test for *E. coli*, an indicator of biological contamination. We traveled to two different districts in the An Giang Province of the Vietnamese Mekong Delta Region, testing six household bottling plants' source and filtered water. In each district, there was one sample that reported unsafe levels of *E. coli* from the piped water. All of the filtered and well water that we tested reported low risk or safe levels. What we initially hypothesized would be a potential problem for the Mekong Delta, may not need further investigation based on our results. The increased level of infrastructure through piped water reaching rural communities and regular government testing of the plastic bottling plants lent itself to safe levels being reported. It is however important to note that our sample size was small, we visited newer bottling facilities, and several people we spoke with still doubt the quality of these decentralized bottling facilities.

In Kenya, with coordination from ACK, we studied households using point of use filters in Western Kenya (Chapter 3). Three different counties were examined based on households that were in possession of their filters. ACK collected information about their access to water, sanitation, and hygiene and Lauren Trepanier water quality data during the Summer of 2019. Throughout her findings, it was evident that the *E. coli* present in different sources of water in Kenya was higher than in Vietnam. Most notably, samples that had been transferred to alternative storage containers reported the most unsafe levels of *E. coli*. This result could have been obtained due to contamination that happens post-filtering. If there is not safe water available, it may not be possible to properly clean cups, storage containers, and the tap the water is being dispensed. In Vietnam, the majority of people we interacted with had access to piped water relatively close to their dwelling. This is not the reality for western Kenya, as people reported anywhere from 0 – 128 minutes required to collect water. These results prove that safe water is a challenge to navigate and universal access is an ambitious goal.

Future research topics could include investigating the relationship between the effectiveness of ACK's filters and the type and quality of the original water sources. Determining exact reasons for cross contamination post-filtering also calls for more studying. Although there is a need for future research regarding SDG 6, it is also important to put plans into action regarding prior studies. The UN notes "Civil society organizations should work to keep governments accountable, invest in water research and development, and promote the inclusion of women, youth and indigenous communities in water resources governance"(11). Achieving universal safe access to water for all will require effort on all fronts; engineers, policymakers, communities, and nonprofits.

Chapter 5

Reflections

As an avid mission trip participant during my middle school and high school years, I developed a special interest in using my resources, talents, and opportunities to help others. I first traveled outside of the United States before my senior year of high school, traveling to Chiapas, the poorest state in Mexico, to help with a Vacation Bible School and participate in a community construction project. It was then that I was first struck with the vast amount of poverty that exists in the world. Traveling from the airport to the small village where we would stay, I experienced my first "culture shock." Growing up in suburban Pittsburgh, I felt relatively sheltered to the immense amount of poverty that exists in our world.

When I arrived at Penn State, I looked for a way to combine my passions of service and engineering. Luckily, I found my community within a group that builds suspended pedestrian footbridges – Engineers in Action (EIA). As a bright-eyed freshman, I quickly befriended all of the upperclassman and made my interest in participating in their summer trip *very* well known. I was selected to be on their travel team to Rwanda which allowed me to spend a month completely integrating into the culture by living and working alongside the community in the collaborative construction of a 61-meter footbridge, our team helped this community gain year-round access to essential markets, healthcare, and education. This rewarding experience led me to specify Civil Engineering as my major because I had discovered my passion of bettering communities through the means of infrastructure.

Progressing through my time at Penn State, I continued to stay involved with EIA and found myself leading a bridge building trip to Bolivia during the Summer of 2019. In Bolivia, I was exposed to the complexities that exist within international development. After a seamless trip in Rwanda, I naively expected smooth sailing in Bolivia. I quickly learned that everything does *not* always go according to plan. After a year of planning to build a bridge in the Puca Huasi community, our team was informed upon our arrival that they no longer wanted a pedestrian bridge in their community and would rather save their money for a vehicular bridge! This humbling lesson taught me that it is important to keep in constant contact with the community, making connections first and not operating under assumptions.

Culture plays a major role in decision making. I experienced this by observing the intricacies that exist in different places around the world. Some communities don't want bridges because they don't want to be connected with the people on the other side. Differing cultures or tribes have fierce alliances to their communities and families. Some communities don't want water sources closer to their home because collecting water is the only time the women can bond with other women in the community. From the outside looking in, it is impossible to determine how specific communities operate. Establishing long lasting, trusting relationships is key to any successful development project. It is one thing to examine what a community may need, but what about what they *want?* Many times, it differs from the American standard way of seeing the world. Along with relationship building prior to traveling, it is important to maintain these relationships upon returning home by continuing to check in with projects and people. It is crucial to teach communities how to operate and maintain the infrastructure that has been created.

In August 2019, I traveled to Vietnam to conduct exploratory research. This was the optimal exercise to focus on talking with people and relationship building. I was welcomed into homes, encouraged to take pictures with children, and offered a variety of exotic fruits. We listened as people told us their struggles with water access and progression in the past few years. We learned how much Vietnamese really care about their health! Some people distrust the water so much they will go through multiple filtering or purification strategies, even with bottled water. Some invest in the technology to filter the water themselves. Throughout the research process, I was reminded of how important it is to focus on relationships first. I learned it is important to be cognizant of any biases within the research process. With the small sample size I was exposed to in Vietnam, it was hard to control for biases. Our sample was not random, we worked off of prior relationships that had been built within the community. In a larger study, certain measures would be necessary, such as controlling for the interviewer, interview questions, and households selected.

These experiences have not even begun to scratch the surface of all of the complexities that exist within international development. When selecting a topic for my thesis, I knew that I needed to connect my passions of engineering and development in some way. As a student completing the Geotechnical and Materials Capstone, pursuing a career in construction, I was excited to dive into a project that I don't necessarily get exposure to in my classes. Studying water resources has given me a greater understanding of all of the intricacies that exist in Civil Engineering and the world as a whole. I was able to connect my past experiences with a new discipline within the field. I was reminded of the value of education, relationship building, and sustainable development. The entire thesis process has been a challenging, yet rewarding one. Even though I have written papers and literature reviews before, nothing compared to the daunting task of writing an entire undergraduate thesis. Students are encouraged during their junior year to nail down our topics to prepare to write during our senior year. At that point, it's hard to envision ever having a complete document worthy of submitting for review. Research and this thesis has taught me discipline and perseverance along with the reward of pure joy!

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EDUCATION

Bachelor of Science in Civil Engineering
The Pennsylvania State University, University Park, PA — Graduation: May 2020
Schreyer Honors College

WORK EXPERIENCE

Project Engineer Intern — May - August 2018
Massaro Construction Group, Pittsburgh, PA

- Organized RFIs, conducted pull-planning meetings, and coordinated with architects and subcontractors for multi-million-dollar renovation and new construction projects such as hospitals, botanical gardens, and apartment complexes
- Managed communication within the Estimating Department to review drawings, complete takeoffs, and contact manufacturers and subcontractors for quotes to develop a $50 million GMP estimate
- Spearheaded sustainability efforts for a Living Building Challenge and LEED Platinum project

ENGINEERING EXPERIENCE

Research Assistant — January 2019- Present
Food-Energy-Water, Critical Infrastructure, and Environmental Lab at Penn State

- Analyzed data trends between socio-economic and environmental factors contributing to poverty
- Traveled to Vietnam (August 2019) to collect data on bottled water quality in the Mekong Delta region

Engineers in Action Bridge Program - Construction of Suspended Bridge
Cochabamba, Bolivia — May - July 2019
Kumusenyi, Rwanda — May - June 2017

- Executed the construction of suspended footbridges over impassible rivers to provide communities access to necessities during the rainy seasons
- Led project with local staff, made logistical arrangements for materials and 20+ volunteers, and managed construction schedule

LEADERSHIP & INVOLVEMENT

American Concrete Institute
Secretary (Penn State Chapter) — May 2019 - Present

- Collaborated with student members, faculty, and professionals to provide educational opportunities and information regarding upcoming events
- Prepared for ACI student competitions by working with ACI officers, student members, and mentors

Engineers in Action
Cross Cultural Competency Committee Chair (National Organization) — June 2019 - Present
Project Manager (Penn State Chapter) — June 2018 – July 2019
Cultural Relations Officer (Penn State Chapter) — June 2017 – June 2018

- Facilitated an online course for international travelers to learn about cultural sensitivity, active listening, and cross-cultural communication
- Composed a Cultural Relations Lessons Learned section for the "Year in Review" document for the National Organization University program

Leadership Development Externships — July-August 2017
BP STEP, Houston, TX
PPG Primers, Pittsburgh, PA

- Explored work and leadership styles to further understand group and workplace dynamics
- Participated in practical learning environments while engaging in engineering related topics

AWARDS & HONORS

John W. Oswald Award for Scholarship	February 2020
ASCE 2020 New Faces of Civil Engineering – Collegiate Edition	February 2020
ACI Concrete Field Testing Technician – Grade I Certification	April 2019
Leonhard Center Speaking Contest Finalist	January 2018
Best Project – Engineering Leadership Development Design Showcase	December 2017