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Associations Between Acute Respiratory Infections, Cooking Fuel Sources, and Climate Change in Cox's Bazar Refugee Camps From 2018-2020

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Abstract

This project investigates drivers of respiratory infections in the world's largest refugee camp, Cox’s Bazar in Bangladesh. Due to the high volume of Rohingya Muslims refugees leaving their home country due to the Myanmar Crisis, the camp is overcrowded, leading to an increase in the spread of non-communicable diseases. This research focuses on the impact of cooking fuels, rainfall, and acute respiratory infections. Environmental changes have the increased potential to add to the spread of respiratory infections in a densely populated and undersupplied refugee camp. Additionally, increased rainfall relates to an increase in the number of refugees in indoor shelters at any given time. Previous studies have investigated the association between fuel sources and rainfall, but not in a complex humanitarian crisis. This

project adds to existing research regarding respiratory infections in Cox's Bazar, and how environmental changes influence these findings.

Introduction

Globally, the number of refugees, including those who are forcibly displaced, has increased significantly. In the early months of 2022, it was recorded there were approximately 27 million refugees in the world, which is a record high (UNHCR, n.d). The world's largest refugee camp, on the Cox's Bazar-Teknaf Peninsula in Bangladesh, was built in 2017 after over 700,000 Rohingya Muslims fled Myanmar during the Rohingya Refugee Crisis (Shammi et. al, 2020). The crisis began when the Myanmar army attacked Rohingya Muslims, causing this already marginalized group to seek protection and take refuge in neighboring and predominantly Muslim Bangladesh, away from the genocide inflicting their country. This influx of people required Bangladesh to quickly build 34 camps, collectively known as Cox's Bazar Refugee Camp, to accommodate the displaced population (UNOCHA, 2018).

Due to the high volume of people and unsanitary conditions, infectious, non-communicable and communicable diseases are prevalent, causing many deaths in the overcrowded camp. One category of the major respiratory illnesses present are acute respiratory infections (ARI) including: bronchiolitis, pneumonia, rhinovirus, influenza, and adenovirus (FIFARMA, 2021). There are also upper respiratory tract infections such as COVID-19, and many others that cause irritation and swelling of the upper respiratory tract (WHO, n.d). In areas of Bangladesh outside of the camp, the prevalence of acute respiratory infections decreased in children under five from 1996-2018 (Hossain et. al, 2022). However, data consistently shows

ARIs are the number one leading cause of death in many refugee camps from areas such as Thailand, Somalia, Sudan, and Honduras (CDC, 2022). Cox's Bazar subsequently reported ARIs as the leading cause of death in the camp (WHO, n.d). Since the inception of the camp in 2017, the mortality and morbidity rates due to acute respiratory illnesses have increased among the residents. According to data collected by the World Health Organization Early Warning and Alert System (EWARS), there was a 13.9% morbidity related to ARIs by the end of 2018 (WHO, 2018). In comparison, for 2022, the latest data shows 17.2% morbidity, demonstrating a steep incline in the morbidity associated with ARIs in the camps (WHO, 2018). Without effective public health measures, there continue to be increased challenges associated with preventing the spread of ARIs in Cox's Bazar.

Cooking fuels options are limited due to the influx of refugees, and resources are becoming restricted due to supply and demand (WHO, 2022). Over time, the source of cooking fuels has changed. When the camp was first built in 2017, most of the population was using firewood (either self-collected or purchased) and other materials from the surrounding area such as animal dung. More recently, there has been a shift toward cooking gas cylinders and biofuels (IOM, 2018-2020). As a result of the high demand for biofuels, the surrounding environment lost many trees due to the use of firewood and the rapid geographic expansion of the camps. In 2017 alone, when the camp at Cox's Bazar was built, around 1,650 hectares of land in the forests were cleared in efforts to produce the camp (Hasan et.al, 2021). With the continuous tree cutting, the forests are in danger of losing biodiversity, and harming species that inhabit these forests. In 2018, liquid petroleum gas stoves and cooking cylinders were made available to approximately 250,000 refugees (IOM, 2018). More cooking gas cylinders have been distributed to the inhabitants of the camp since then (IOM 2018-2020).

Along with loss of forests and air pollution, climate change is a significant global challenge. With climate change, the frequency of precipitation is altered. The area in Bangladesh where Cox's Bazar is located receives high amounts of precipitation, averaging around 2,200 mm of rainfall per year (World Bank Group). To put this into perspective, Vermont receives around 934 mm of rainfall per year (World Climate, 2022). Along with the prevalence of extreme rainfall, Cox's Bazar was haphazardly built on slopes, which when combined with heavy rainfall, presents a significant risk of landslides (Cousins, 2018).

This thesis aims to determine potential drivers of the increase of respiratory illnesses in Cox's Bazar. There are poor surveillance systems in the camp, and limited resources are accessible to refugees. This work will provide remote surveillance data to help camp administrators prepare for health care needs resulting from climate change. Therefore, I will evaluate the association between cooking fuels, rainfall and acute respiratory infections in the world's largest refugee camp. My hypothesis will demonstrate that increased rainfall combined with the use of cooking fuels indoors, both serve as a catalyst for the surge in acute respiratory infections in Cox's Bazar.

Site/Context

The vast majority of the inhabitants in the refugee camps within Cox's Bazar self-identify as Rohingya (UNHCR, n.d). This community is predominantly Muslim and speaks an Indo-Aryan language also known as Ruaingga, and made up a sizable minority within the Rakhine state prior to the recent ethnic-cleansing (Al Jazerra, 2018). Within this region of Myanmar, previously (and still by the Rohingya) named Arkan, there was a long standing Muslim community. This community, however, was historically very small in comparison to the

Buddhist Rakhine (Al Jazerra, 2018). During the British colonial period where there was no real practical border between Burma and British India, the Muslim population in this region grew tremendously due to migrations from modern southern Bangladesh (Al Jazerra, 2018). The Rohingya community absorbed these newcomers who largely shared the same religion and language. This dramatic demographic shift resulted in increasing ethnic and religious strife within Arkan. (Al Jazeera, 2018).

The first large-scale outbreak of inter-community violence came within the environment of the Second World War (United States Department of State). Japan successfully invaded much of Burma in 1942 and maintained a degree of support from many groups within the region, as it attempted to portray the war as an anti-imperialist struggle within the entirety of Asia (Pearn, 1945). As such, the broader war allowed for these ethnic tensions to escalate to pogroms. The Rohingya largely sided with the British, who created armed formations meant to combat the Japanese within Burma (Pearn, 1945). The Buddhist communities in Arkan largely supported the Japanese war effort, and likewise were armed. There were many instances of communal violence on both sides, resulting in the deaths of thousands (Pearn, 1945). Many Rohingya, alongside British citizens and migrants from other areas of the colonial territories, fled to Bangladesh (United States Department of State, n.d).

With the British withdrawal from the Indian Subcontinent in 1947, the Burmese government rather rapidly became authoritarian, with the Tatmadaw (the Burmese military) gaining considerable political influence (Bhaumik, 2007). Since independence, the military has seized complete power several times, and also been the kingmaker when democratic life returns (Bhaumik, 2007). Part of the key to success has been the military creating an environment which necessitates this overwhelming political influence. The ethnic tensions and conflict within

Rakhine state are not unique within Myanmar (which the military dictatorship renamed the country in English), which is home to a variety of ethnic groups. These circumstances allow for the military to justify its size and influence in the country, as it prevents its disintegration and maintains a Buddhist and Bamar dominated state (Bhaumik, 2007). A citizenship law in 1982 by the military stripped most of the Rohingya of their citizenship, a clear sign of the intention for their future (Bangladesh State Department, 2021).

In the most recent surge of violence in Rakhine state, the military is often accused of actively fomenting the unrest by local Buddhists against the Rohingya (Albert and Mainsland, 2020). Large scale communal violence, and violence perpetrated by the state itself has led to the deaths of thousands and the displacement of hundreds of thousands who have fled primarily to neighboring Bangladesh.

Image 1: An image depicting the violence in Burma, which caused many of the Rohingya to flee Bangladesh. Fire was set to many villages (Fisher, 2017).

From the Norwegian Refugee Council, a quote from Nurul Amin, a refugee from Burma: "When the Myanmar military attacked my home, I lost four of my closest family members; my father, my brother, my sister and one of my nephews. Everything I owned was burned down – I've lost everything" (Kolstad, 2018). In 2017, many fled to Cox's Bazar due to these horrific circumstances and made makeshift settlements, with barely enough resources to survive, due to the overwhelming influx of refugees. With this influx of people, and lack of housing, the situation was declared an official crisis a few months later in 2017 (UNHCR, n.d). In the beginning, the most populous areas of Cox's Bazar were Nayapara and Kutupalong (UNHCR, n.d). The camp continued to expand with more sites being built to accommodate the exorbitant number of people fleeing to Cox's Bazar. During the expansion of the camp, many of the trees in forests in the area were cut down to make room for homes, as well as used for fuel sources. In 2018, there were monsoons which caused dangerous landslides (UNHCR, n.d). As a result of the overcrowding in these areas, many were affected and harmed (UNHCR, n.d). This caused more camps within the region to continue to be built, and people to move to safer areas where they would not fall victim to the landslides (UNHCR, n.d). This is an ongoing battle, as overcrowding is a significant problem in the camp, and many organizations are working to resettle and make areas where people and houses will be safer.

Image 2: A photograph from the Kutupalong camp in Cox's Bazar. Seen in the image is one of the main roads, surrounded by makeshift homes. Some of these homes are on hills, and others closer to the water (UNICEF, n.d.).

The population of Cox's Bazar is composed of people from different religious and ethnic backgrounds (Bangladesh State Department, 2021). Within the camp, there are people of the following religions: Muslim (predominant), Hindu. Buddhist, Christian (minority) and more (Bangladesh State Department, 2021). These identities are an integral part of the social and cultural lives of the refugees in Cox's Bazar. There are leaders for all of the religions in the camp, who are highly respected individuals of the community (Bangladesh State Department, 2021). These leaders could have roles in socialization, communication with the community, positive behaviors, and control of many actions that could occur in the camp (UNHCR, n.d).

The demographics of Cox's Bazar include nearly one million individuals across all of the camps (UNHCR, n.d). As of 2022, among the one million people, approximately 52% were children, 44% were adults, and 4% were elderly (UNHCR, 2022). The division of the population is approximately 52% who identify as female, and 48% who identify as male (UNHCR, 2022). Additionally, there was an average family size of five (UNHCR, 2022). It is crucial to note, this camp has exceeded its capacity, leaving many with scarce resources such as no access to clean water, healthcare, and many other factors vital for survival.

Image 3: A photograph of refugees living in the refugee camps from Cox's Bazar. They are building makeshift homes (UNICEF, n.d.).

Due to the influx of refugees from the Myanmar crisis, the Government of Bangladesh built camps quickly to accommodate the rapidly increased population. Cox's Bazar comprises approximately 28 different refugee camp sites on the Teknaf-Uhkia peninsula, as seen in image three, making it a vast and complex network (WHO, n.d). These different camps inside the so-called "mega camp" have a wide range of populations. It is located in South-East Bangladesh, with some of the camps closer to the shoreline and beaches, and others closer to areas with more grassland as depicted by Images 4 and 5 (Alam et. al, 1999). In the coastal areas, shrimping, fishing, and many agricultural processes benefit the economy (Alam et. al, 1999). These coastal areas are extremely vulnerable to water rise and flooding, especially with the high levels of rainfall in the area (Alam et. al, 1999). This can be rather dangerous to those living in the area, and can harm resources and people living along the coast (Alam et. al, 1999). There are also different elevations along the coastal plain as well, with lower elevations being closer to the beach, and higher elevations further away from the shoreline (Alam et. al, 1999). A part of these lower elevations include muddy flats, also prone to flooding (Alam et. al, 1999). The higher elevations on this coastal portion are more prone to forceful winds, and cyclones, which can also have detrimental impacts on the environment, people and resources (Alam et. al, 1999). There are also grassland areas more prone to landslides (Adnan et. al, 2020). Landslides are just as fear-provoking as flooding to the residents in the camp (Adnan et. al, 2020). Therefore, both of these conditions, whether closer to the coast or closer to land, have their own topographical challenges. As seen in Image 4, the Ukhia region camps are located further off the coast, and the Teknaf regions are located closer to a body of water.

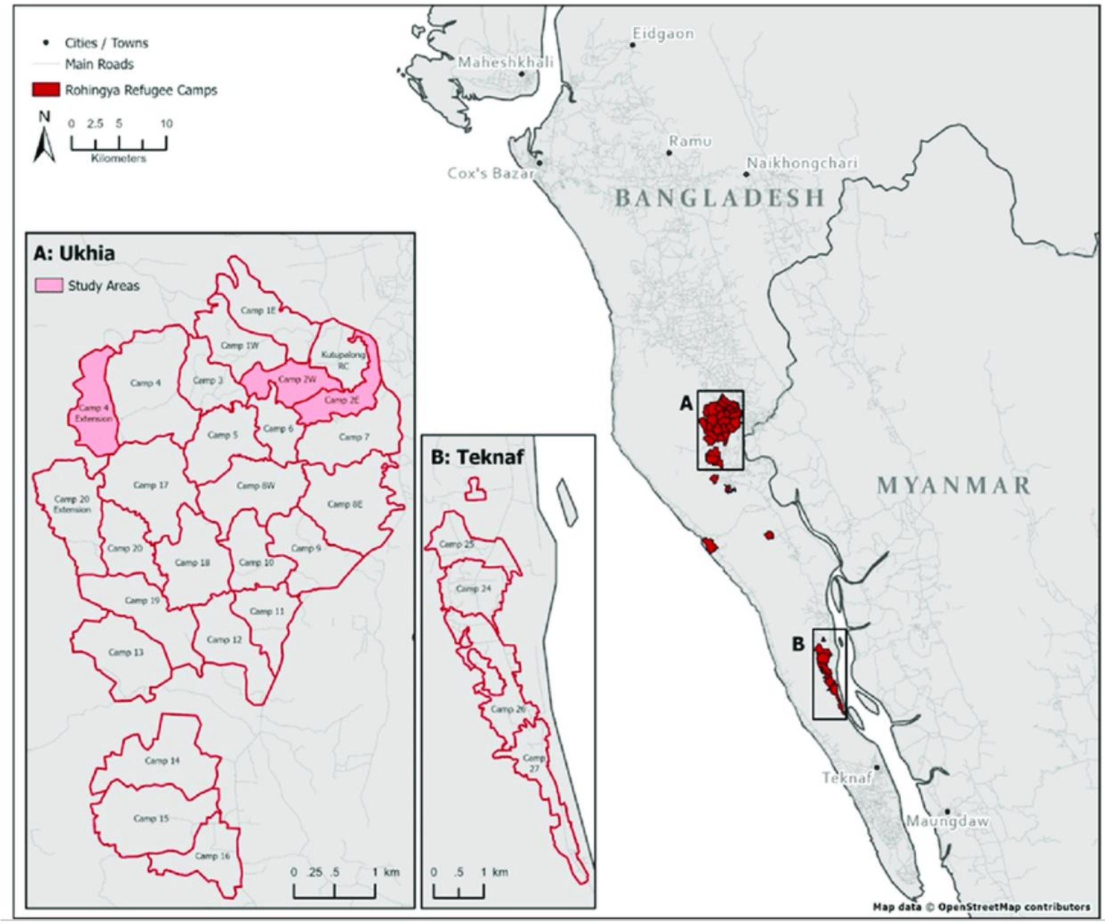


Image 4: A map depicting the area of Cox's Bazar where the Teknaf-Ukhia Peninsula is located, home to 28 different camps. (Akhter et. al, 2020)

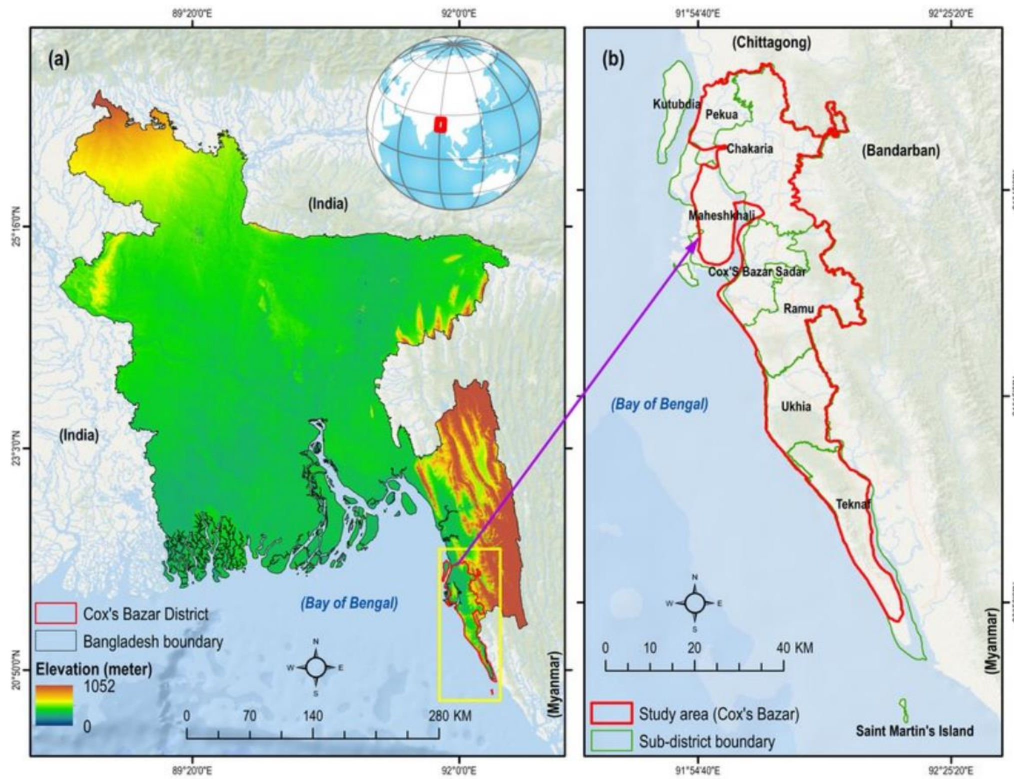


Image 5: A map depicting the regions in Cox's Bazar, and their associated elevations. On the southern coast there is Ukhia and Tekaf, where all of the camps are located. Most of this area is in the green elevation zone (Adan et. al, 2020).

In addition to the topographical challenges associated with the landscape, the unstable materials in which the makeshift homes are built cannot withstand the environmental conditions. These homes are made from bamboo, tarpaulin, tin and plastic, and many other resources available in the environment (Islam et. al, 2022). This poses more danger to the refugees housed in the camp, as their shelters do not have the ability to provide protection from the environmental disasters they are exposed to (Islam et. al, 2022). Undoubtedly, due to these factors, not many individuals feel safe in the camp, and instead, they live in constant fear of these environmental disaster events.

Image 6: An image depicting the overcrowding of the camp and taking cover during the rain (UNHCR, 2017).

Respiratory infections can be highly transmissible, such as diphtheria and COVID-19, particularly in areas of high population with overcrowded conditions (Dasaraju and Liu, 1996). From the inception of the camp in 2017, there has not been any research conducted on a possible relationship between ARIs, cooking fuel source, and rainfall, but it is important for this research to be conducted in Cox's Bazar. Due to the significant mortality rates for acute respiratory infections in the camp, it is important to determine possible explanations of the cause. The WHO includes both upper respiratory tract infections, as well as lower respiratory tract infections in their definition of ARI (WHO, n.d). This is where the data was collected, so this definition was used throughout the study, accounting for both conditions.

This research can be used in promoting health through the creation of public health measures regarding what fuel sources, and whether indoor or outdoor cooking is more efficient.

It accounts for the fuels available to the refugees, the efficiency of those fuels, and the health effects of burning such fuels. In order to improve air quality in the camp and lessen the risk for acute respiratory infections, it can be determined if there should be different rooms designated for cooking, and assess the ventilation in the indoor shelters.

Previous Works/Literature Review

There are many previous works that studied the population of Cox's Bazar camp; however, none of these studies have specifically examined the relationship between rainfall and acute respiratory infections in the camp. Previous studies have focused on fuel sources, rainfall, and the implications of these factors on climate change (Admaise et. al, 2018) (Janjua et. al, 2012) (Zandvoort et. al, 2022).), but not in the Cox's Bazar area. For example, a study was conducted in Southern Ethiopia, on how poor ventilation in homes can be a greater risk factor for acute respiratory infections (Admasie et.al, 2018). This is important for future residents of the camp as more public health measures can be implemented to lessen the impact of cooking fuels on overall health.

<u>Acute Respiratory Infections</u>

The high prevalence rates of acute respiratory infections in a refugee camp are not unique to Cox's Bazar. Due to poor sanitation standards and the crowded conditions in which they live, refugees are more susceptible to these infections (Jablonka et.al, 2021). It is known that indoor air pollution can develop from different cooking fuel sources, and is a significant risk factor relating to pneumonia, contributing to 22% of adult deaths worldwide (World Health Organization, 2022). In a study conducted in a refugee camp in Germany, it was determined that acute respiratory infections were the leading cause for refugees to seek medical care (Sehgal et.

al, 2014). In one of the studies conducted in Cox's Bazar, it was found there were many outbreaks of diphtheria, a communicable acute respiratory infection (Shammi, 2020).

Additionally, in a study conducted in an internally displaced persons camp in Somaliland, it was shown that ARIs have a significant impact on those in the camp (Zandvoort et. al, 2022). This is also considered to be an overcrowded, undersupplied camp, with a high prevalence for physical touch and contact (Zandvoort et. al, 2022). This particular mainly focused on pneumonia, with the most common cooking fuel sources used in the camp were charcoal and firewood, both solid fuels (Zandvoort et. al, 2022). The under five population of the refugee camp was severely impacted by pneumonia. It was found that 42.8% of the under two population had self-reported pneumonia (Zandvoort et. al, 2022). Conversely, 26% of the two- to five-year-olds in the camp also had self-reported pneumonia (Zandvoort et. al, 2022). There are more cases found across all of the age groups as well, further proving the impact of ARIs in another refugee camp.

In another study located in rural Pakistan, there was an investigation surrounding acute respiratory infections and episodes that come with them (Janjua et. al, 2012). Of those surveyed, it was found that 45.2% of them experienced a respiratory episode in the past month (Janjua et. al, 2012). A potential cause of this high risk of acute respiratory infections in Pakistan can be correlated with a higher biomass use in the households of those impacted (Janjua et. al, 2012) A significant number of the population is experiencing respiratory distress among all age groups. However, approximately 46% of those aged five and under who were surveyed experienced these respiratory distress syndromes as well (Janjua et. al, 2012). Undoubtedly, acute respiratory infections have a severe impact on individuals of all ages, with a more significant impact in those under five.

Additionally, from the Journal of Environment and Earth Science, there was an investigation of the fuel use and acute respiratory infections in children under five, in Gondar, Ethiopia (Alemayehu, 2014). This study was used to determine the impact of biomass fuels such as firewood, dung and coal in Ethiopia (Alemayehu, 2014). As found from the study, there were more acute respiratory infections associated with biomass fuels, than there were with "greener" fuels such as liquid petroleum gas (Alemayehu, 2014). These biomass particles can travel deep into the lungs, and eventually lead to conditions such as respiratory infections, coughing, and shortness of breath. This could explain the statistics associated with fatalities from acute respiratory infections in children five and younger as children do not have a fully developed respiratory system, which results in a vulnerability to these small air particles. Their airways and lungs are still developing along with immune defenses that would normally increase mucus production to push the pathogen out of the body.

Fuel Sources in Cox's Bazar

The burning of fuel is essential for the survival of refugees in the Cox's Bazar camp, mainly for cooking (Hossain and Moniruzzaman, 2021). The primary source of fuel in Cox's Bazar comes from firewood biomass (Al–Artat–Bin–Ali and Khatun, 2018). With the influx of refugees in 2017, a more dramatic toll was taken on the forest, leading to further degradation. Some of the tallest tree species, Boilam and mixed evergreen trees, were cut down to support the livelihood of the Rohingya refugees (Hasan et.al, 2021). In addition, refugees have also used animal dung found in their surroundings (IOM, 2018). Resources for alternative fuel sources are limited, and refugees in the camp are highly dependent on this fuel for cooking and heating purposes (Al–Artat–Bin–Ali and Khatun, 2018). Another source of fuel for the camp, from household data as collected from the IOM, was found to be a cooking gas cylinder (IOM, 2018).

Cooking fuel and firewood are in short supply and represent a severe need for many inhabitants of the camp (IOM, 2018).

Though fuel is necessary for refugees' survival, it can also be detrimental to the environment and the health of the refugees. A recent study conducted in Cameroon identified when using firewood as a fuel source, chronic bronchitis was found in 7.6% of individuals, but only in 0.6% of individuals who used alternative fuels (Ngahane et. al, 2021). It was also noted that fuel from biomass ranks tenth for preventable negative health outcomes (Ngahane et. al, 2021). This means of all the risk factors for disease, biomass fuel is listed tenth for preventability. Biomass fuel is a cheap and rather accessible source, but can lead to detrimental health impacts (Sehgal et. al, 2014). It is known that biomass fuel relates to air pollution, due to improper combustion (Sehgal et. al, 2014)

The WHO determined that there are 3.2 million deaths each year due to unsanitary cookstoves and those jeopardized by smoke (WHO, 2022). Further research is needed to determine the most efficient sanitation methods for the cooking stoves. In a study conducted in Cox’s Bazar during the COVID-19 pandemic, it was found the air particulate matter increased in areas where biomass and gas cooking stoves were used (Shammi et. al, 2020). This relates to reduced air quality in the camp, which is a risk factor for acute respiratory infections (WHO, 2022). Moreover, cooking gas cylinders, a cleaner alternative to biofuel, can be tied to air pollution, which can have significant health impacts, especially those relating to the respiratory system (Del-Rio et. al, 2017).

From a study conducted in Kenya, the importance of research on acute respiratory infections was shown (Ezzati and Kamen, 2001). One covariate involved was the average daily

PM_{10} levels which were newly introduced covariates in comparison to any of the previous literature investigated. PM_{10} can be explained as air particles with a diameter of 10 micrometers or less, and can be inhaled directly into the lungs, making them dangerous. There are also $PM_{2.5}$ which are particles with a diameter of 2.5 micrometers or less, which are also dangerous when inhaled. These particles are widely associated with air pollution, and this study looked into the association of these daily levels with biomass cooking fuels (Ezzati and Kamen, 2001). This is because some of the particles which are usually associated with PM_{10} are smoke, dust, soot, etc, which can all be created as a result of fire burning from biomass fuel sources.

Rainfall in Cox's Bazar

In Cox's Bazar, there are many landslide events due to the rainfall observed, and the construction of the camp in general (Kamal et al, 2022). During a specific landslide event during July, 2021, there was about 300 mm of intense rainfall, which is considered a large amount (Kamal et al, 2022). The landslides have the ability to flood, wash away materials, and much more, causing temporary shelter adjustments (Kamal et al, 2022). The water people are exposed to during flooding is unsanitary, and can contain many bacterial agents. If these individuals impacted by the flooding did not partake in hygiene methods such as showering and handwashing, and touched the water, their immune system could be compromised.

It is known that in more tropical climates, where rain is more prevalent, there is an increased risk for acute respiratory infections (Murray et al, 2011). This particular study was conducted in Dhaka, Bangladesh (Murray et al, 2011). There was an association found between rainfall and acute respiratory infections when there were more than three people per room, and no association when there were less than three people (Murray et al, 2011). This can be explained as when it is raining frequently, more activities must be moved inside, causing crowded conditions. These crowded conditions cause a higher risk of transmission. Respiratory infections can be transmitted through droplets, and with many individuals in a tight space, and less than five feet of distance between them, there is a higher risk of acquiring the infection. These infected individuals may not know they are sick or have a serious respiratory infection and therefore do not isolate themselves from others. This is dangerous during the infectious window of respective respiratory infections. Also, in general, the cold, damp rain is known to harm the immune response, impacting the body's most powerful defense mechanism against foreign pathogens (Nwaogu, 2019).

One of the areas specifically included in a study on variation of temperature and rainfall in Bangladesh was Cox's Bazar, the location of the refugee camp being studied (Rahman et al, 2015). This illustrates how major factors of climate change include precipitation and temperature, and is most prevalent in underdeveloped/developing countries (Rahman et al, 2015). The general climate in Bangladesh includes heavy rainfall, extreme humidity and heat (Rahman et al, 2015). The study identified the main seasons evaluated in Bangladesh across the regions. These seasons included three most prevalent: hot summer, hot and humid (monsoon), and cool and dry winter (Rahman et al, 2015).

Diet and Nutrition

There are many factors such as diet and nutrition which also have an impact on the occurrence of acute respiratory infections most significantly in low-income countries such as Bangladesh (Khatun et al, 2022). For instance, in a specific study conducted by Cox's Bazar

Medical College, it was researched if there was a correlation between those admitted with acute exacerbations of chronic obstructive pulmonary disease, an inflammatory lung disease, and vitamin D levels (Khatun et al, 2022). Vitamin D can be found in eggs, cheese, mushrooms, fatty fish (such as salmon), mushroom, milk and orange juice. These foods are not abundant in low-income countries, especially in refugee camps. As a result of the study, it was found vitamin D deficiencies were correlated with acute exacerbations of chronic obstructive pulmonary disease (Khatun et al, 2022). Undoubtedly, a healthy, nutrient rich diet is important for optimal body functioning and can lead to disease, such as acute respiratory infections.

Another study was conducted on the sources of air pollution and effects on children aged three years and younger in India (Mishra et. al, 2005). Covariates used in this study were the gender of those affected, birth order of the child, mother's age at childbirth, nutritional status, tribe, house type, and many more (Mishra et. al, 2005). The most significant effects which led to occurrences of acute respiratory infections in this particular study were the fuel source (solid cooking fuels increased cases), age of the child, gender, age of mother at childbirth, and economic status (Mishra et. al, 2005). The only covariate that could be included from this study was the nutritional status of the child, which was taken from the WHO on fatalities associated with severe malnourishment.

It was important to track whether the child was breastfed, or not, in a study from New Delhi (Boor et. al, 2001). Nutritional status was found to be statistically significant, regarding whether the child was breastfed in the first four months of life (Boor et. al, 2001). Potential reasoning for this would include a stronger immune system associated with breastfeeding, and the establishment of a microbiome. This microbiome includes commensal microbiota that strengthens many processes within the body, including immune protection and signaling. If this communication system is not established, when the body encounters a foreign pathogen, it will be unable to recruit the necessary helpers.

Access to Immunizations/Medicine

In a study conducted in urban slums of the Delhi, Kusumpur Pahari and Kathputli colonies on acute lower respiratory infections used household surveys for the determination of chosen fuel source, distance from the nearest industrial complexes, distance from air quality stations and house types (Sharma et. al, 1998). Interestingly, to further analyze, the researchers chose one high population slum, and one with a lower population to determine the impact of population on the occurrence of acute respiratory infections (Sharma et. al, 1998). Covariates used in this study included: age, nutritional status, recordings of acute lower respiratory infection episodes, sex, parental education statuses, parental occupations, family size, immunization status and siblings (Sharma et. al, 1998). Immunization status was also an important covariate used in the study, and which medications were accessible in the area that could be used to treat certain ARIs (Sharma et. al, 1998) This is an important factor as adults and children who do not have proper vaccinations would be at risk for otherwise rather preventable illnesses.

Another study conducted by the department of pediatrics in New Delhi, India on potential factors for the cause of severe respiratory tract infections in children aged five and under (Boor et. al, 2001). For this study, covariates included: age, sex, age of parents, parental education status, immunizations, family history, many factors influencing nutritional status of the children, fuel sources, and if there are any smokers in the household (Boor et. al, 2001). From this study, whether there was access to immunizations and medicine could be used, as it was found immunization did correlate with lower acute respiratory infection cases (Boor et. al, 2001).

Possible reasoning for this result could possibly be correlated with a higher education status of the parent, which could result in detection of warning signs for a developing respiratory infection and early intervention at a hospital (Boor et. al, 2001).

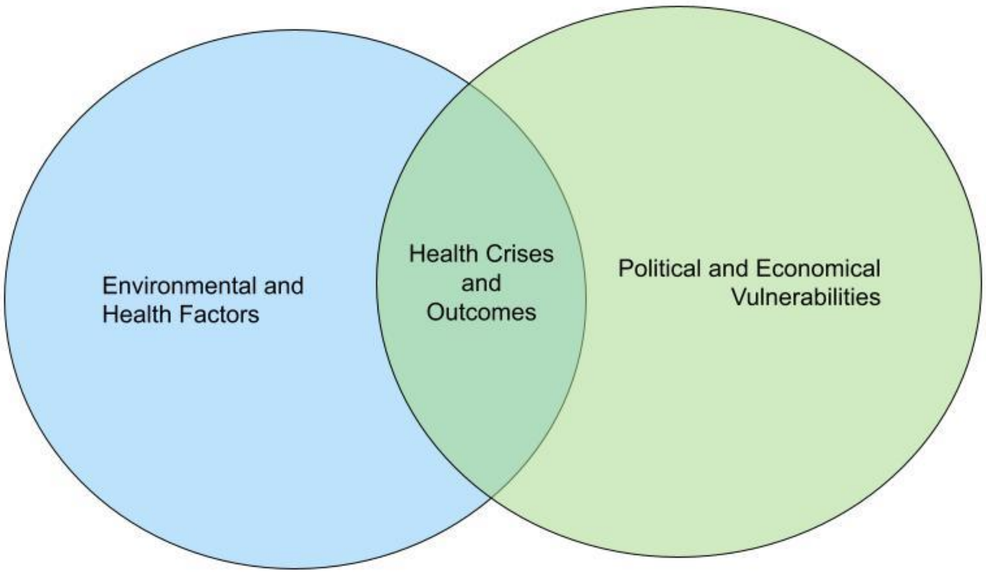
Water Sources/Access

For water access, there was a study conducted in Alaska, in which acute respiratory infections were investigated, along with the water sources for these individuals (Hennessy et al, 2008). More specifically, in the study, there was importance on whether the water source was from in-home piping, or not, and what the wastewater treatment system is like in the area (Hennessy et al, 2008). There was access to this data from the Needs and Population Monitoring Survey, which shows specifications for whether the source of water is improved or unimproved. This means whether the water is exposed to the environment or contained. Essentially, as a result of the study, it was found when there were more sanitation methods taken before the use of water, there was generally a decreased risk for diseases, including acute respiratory infections such as pneumonia (Hennessy et al, 2008). From the results of this study, it can be seen that access to clean water not only helps with hygienic measures, but also hydrating the body to function (Hennessy et al, 2008). Although acute respiratory infections are not easily transmissible person to person, if there is no access to clean water to wash hands, or has not been sanitized, it could compromise the individual’s immune system. Immunology is a game of numbers, and the more cells that can be recruited to the site of infection, the faster it can be cleared. If the drinking water contains other harmful pathogens, then the system will be divided, and unable to produce a robust response against the infectious agent. Water is also used in many of the biochemical pathways of the body, and when it is not present, these processes cannot be carried out. This impacts communication in the immune system, as the integrity of the mucous membranes is not as strong when not fully hydrated. Undoubtedly, this allows for foreign pathogens to enter the body, and colonize.

Latrine Access

For latrine access, there was a study conducted in rural Bangladesh that investigated the effect of sanitation methods on general hygiene of individuals, and if there was a correlation of improvements with lessened acute respiratory infection prevalence (Ashraf et. al, 2020). Most of those surveyed did not have access to clean latrines, and the study aimed to sanitize, and add soap (Ashraf et. al, 2020). There was also a clear distinction made between those defecating outside, and those that had access to a latrine (Ashraf et. al, 2020). While looking at the latrine data collected, there were conditions such as whether there was visible stool in the latrine, in the house, and in the play area of the homes (Ashraf et. al, 2020). It was found that when there were sanitation methods implemented for a cleaner latrine, the incidences of acute respiratory infections decreased (Ashraf et. al, 2020). There are many plausible explanations for this result, as in feces, there is a high concentration of bacteria and microbes. Some of these bacteria and microbes can be beneficial for the body, and others are not. The bacteria and microbes in the latrines and getting tracked into people's homes, can be detrimental for those individuals. Along with feces in the home, if these individuals are not washing their hands and home properly, there is a greater risk for infections and disease in general. Therefore, if someone is already sick and then exposed to an individual with a case of pneumonia, there is a higher risk for transmission due to the vulnerability of the body.

Conceptual Model



Conceptual Model 1: A model with environmental and health factors (blue) and political and economic vulnerabilities (green) with an overlap at health crises and outcomes.

The overarching ideas presented between covariates, rainfall ARIs, cooking fuel sources, and other conditions in the camp can be combined into three categories: environment and health factors, health crises and outcomes, and political and economical vulnerabilities (Conceptual Model 1). The environmental and health factors are comprised of landslides, deforestation, flooding, water sources, latrine access, access to immunizations/medicine, cooking fuel sources, and severe malnourishment. The political and economical vulnerabilities are comprised of the military predominantly running the camp, socioeconomic status, and religion. At the heart of both categories are health crises and outcomes, which includes the leading cause of death in the camp, ARIs, as well as severe malnourishment.

These can be grouped in this manner due to political and economic vulnerabilities and environmental and health factors contributing to overcrowding specifically in Cox's Bazar. When there are landslides, and other natural disasters, refugees must flee to a neighboring shelter for safety. Similarly, many of those in the camp have come as a result of political conflict, resulting in refugees having very few personal belongings or money. All these factors lead to health crises and outcomes, as overcrowding can perpetuate disease spread, scarce resources, little to no ability to support themselves, and much more.

Methods

Data Collection

First, to obtain the data that was used for these findings, the Humanitarian Data Exchange Needs and Population site assessments in Bangladesh were used (IOM 2018-2020). One site assessment was used per year for quantitative data. From the same data source, for each of the years, the following conditions were tracked: fuel sources, access to water, immunizations/medicine, and latrines. These variables were tracked on a monthly basis, and averaged for the year. The covariates used for this study were found during an extensive literary review. To organize this data, a table was made for each of the years with these variables (Tables 1 and 2). The variables were coded for ease in keeping track of how many people reported each of the conditions out of the population surveyed. This allowed for the quantification and visualization of change in those surveyed over time. While monitoring these changes, it was important to note this data set is a small portion of the total refugee camp, and it could not be determined if those living in the households surveyed were diagnosed with acute respiratory infections.

Acute respiratory infection and severely malnourishment data were collected weekly between 2018 and 2020 from the Early Warning Alert Response System (EWARS) Bangladesh. These values were collected weekly in terms of how many fatalities there were divided by the whole population, and the weeks were then averaged per year. For this data it is important to note these fatalities were only based on those reported, and the total population may be slightly inaccurate due to the poor monitoring and surveillance systems of the camp.

The *rainfall* data was collected weekly from 2019-2020 by a student in the Gleason research lab with the use of geographic information system (GIS) data.

For the collection of *fuel source* data, all data was obtained from the Humanitarian Data Exchange Needs and Population Monitoring. There were many different categories for this variable, including self-collected firewood, purchased firewood, dried animal dung/manure, cooking gas cylinders, unspecified firewood, and others. None of these categories were grouped together, as there were differences among each of them. Although it may seem as though all of the firewood could be grouped together, it was of importance to keep track of self-collected and purchased firewood separately, as there are differences. Purchased firewood is usually kiln-dried or heat treated (US Department of Agriculture, 2022). This is important, because those who collected the firewood themselves do not know proper technique, the wood may be moist or have other pesticides/chemicals on them (US Department of Agriculture, 2022). This can be dangerous if inhaled, which is why purchased firewood is a better choice between the two.

Unspecified firewood was left in a separate category, as well as other, since there was no clear cut category to combine them.

For the collection of *water source/access* from the humanitarian data exchange, similar distinctions needed to be made in the coding process. According to the WHO, improved water sources include those such as water that is protected from features of the outside environment (WHO, n.d). Furthermore, these resources include protected springs and other bodies of water, rainwater collection and in-house water sources (WHO, n.d). From these definitions, it was found that the terms improved and protected can be used interchangeably, making those survey responses able to be combined. For the unimproved water sources, these include unprotected bodies of water, bottled water, and surface water (WHO, n.d). From there, unimproved, and unprotected water sources were also combined in the coding process. For the improved sources the following variables were combined: improved tube wells hand pump, improved storage tanks tap stand, improved piped water tap stand, and improved protected spring. For the non-improved sources, the following variables were combined: no water access, non-improved unprotected well, don't know, non-improved surface water, tube wells/hand pump, piped water tap/ tap stand, storage tanks tap/ tap stand, unprotected spring, unprotected well, non-improved unprotected spring, surface water, pond, and stream etc.

For *latrine access* data from the humanitarian data exchange needs and population monitoring, there were only 2 categories that were coded for, access and no access. There was the same simplicity in the coding for *access to immunizations/medicine,* and there was either access or no access.

Data Analysis

For the comparison of these covariates with the acute respiratory infection fatalities and morbidity, the data was read into R and R studio. A linear regression with ARIs as the outcome variable was created and included measures of, malnourishment, rainfall, and total population, as covariates with weekly data. For the first model, the linear regression was done without accounting for seasonality and time. This was corrected for the second model to account for differences across time, and increased accuracy. The code for the data analysis in the study was co-created with my advisor, Dr. Kelsey Gleason.

The data were evaluated, and it was ensured that R and R studio was updated before coding began. The weekly variables for the experiment were placed in a separate dataset, with zeros added in places where there was no data found. This is where the acute respiratory infection (ARI) cases are compared to malnourishment, rainfall, and total population data. Where time was not included, this was known as Model 1 in R. The linear regression equation is the following:

Original Equation: $Y = \alpha + \beta X + e$

Equation from dataset: ARI = + α + β(malnourishment) + β(rainfall) + β(total population) + e

The Y variable in the equation stands for the predictor variable, or the variable that is being tested for. In this study, ARI cases are the predictor variables. The variable in the equation stands for the value of the Y when the X variable is equal to 0. This would be the value of ARI cases when the value of the independent variables (malnourishment, rainfall, total population) are equal to 0. Lastly the e variable accounts for any potential error that could be associated with the ability of the independent variables to predict the outcome for the variable being tested for. In R, for Model 1, this equation was used three separate times to account for the three independent variables. For all of the equations, ARI cases were known as the Y variable. The X variable was altered to allow for results for malnourishment, rainfall, and total population. This data would aid in the prediction of a potential correlation with the independent variables and ARI cases.

For Model 2, time was accounted for with use of a time series regression. In the new excel spreadsheet that was used for the incorporation of the data into R, a column entitled "Weeks Since 2018" was included. ARI cases and time were now the predictor variables, and compared with malnourishment, rainfall, and the total population. This would account for any potential variation among the ARI cases from 2018-2020. Equation including time was the following:

Equation for time regression: ARI = time + α + β(malnourishment) + β(rainfall) + β(total population) + e

All results from the R and R studio linear regressions, were reviewed with Dr. Gleason. These interpretations were used for the following analysis in the determination of which covariates were statistically significant in comparison to ARI cases, and if time played a role.

For the covariates where there was only monthly data, the change over time was demonstrated visually by using bar graphs. For this portion of analysis, Maria Sckolnick, who offers statistics help at the library, was consulted. During this meeting, the overall goals of the thesis project with the dataset given was explained. Unfortunately, there was not enough data to complete a linear regression, as there was not enough data available. Despite there being many covariates that could have been accounted for, there only being three years of data, which was not enough to complete the task. Therefore, it was recommended this change over time be shown graphically by making bar graphs in Excel. The ARI cases per year could be used, and show how each variable changes per year, in comparison with the ARI cases. This would also show a visual comparison of the fuel sources and their change over time.

Results and Discussion

It was initially hypothesized that rainfall, cooking fuels, severe malnourishment, water source/access, latrine access, and access to immunizations/medicine, would all impact acute respiratory infections in Cox's Bazar. Throughout the duration of the study, 2018-2020, acute respiratory infections were consistently the largest cause of death in the camp.

Tables

Year	% Cases of ARI	% Severly Malnourished	% Fuel Type 0	% Fuel Type 1	% Fuel Type 2	% Fuel Type 3	% Fuel Type 4	% Fuel Type 5	% Fuel Type 6
2018	0.91%	0.01%	53.98%	32.01%	10.03%	1.53%	2.51%	0.00%	0.00%
2019	1.29%	0.01%	0.00%	0.00%	0.00%	0.00%	99.59%	0.41%	0.00%
2020	1.25%	0.00%	0.00%	0.00%	0.00%	0.00%	99.84%	0.00%	0.16%

Table 1: Part 1 of the summary statistics table, showing each average for the years. This data was kept track of monthly, and for ARI and average precipitation, the average was taken for each year.

Year	% Access to Immunizations	% No Access to Immunizations	% of No Water Access	% of Improved Water Source	% of Nonimproved Water Source	% No Latrine Access	% Latrine Access	Average Rainfall (mL)
2018	5.94%	94.06%	8.29%	87.30%	4.69%	53.22%	46.78%	No Data
2019	8.97%	91.03%	0.82%	0.31%	99.13%	56.92%	43.08%	2.2
2020	16.81%	83.19%	0.32%	0.00%	99.68%	57.20%	42.80%	10.04

Table 2: Part 2 of the summary statistics table, showing each average for the years. This data was kept track of monthly, and for ARI and average precipitation, the average was taken for each year.

<u>Graphical</u>

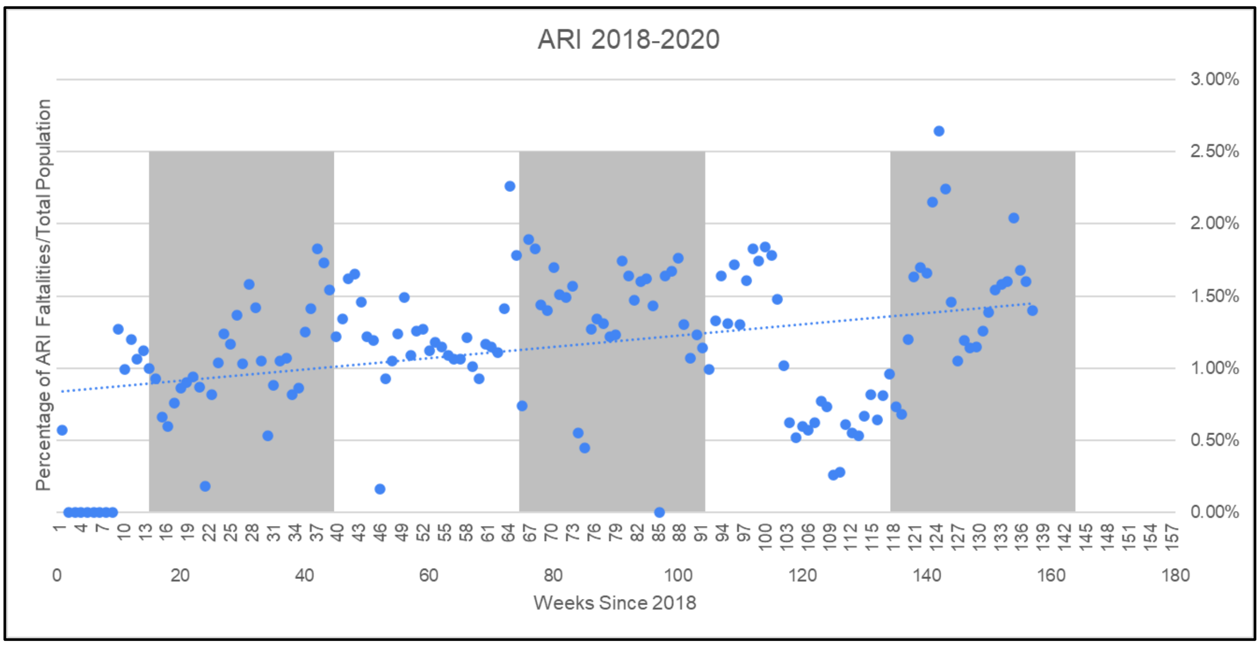


Figure 1. The total acute respiratory infection cases divided by the population as shown through the weeks since 2018, week 1 through week 157. The shaded gray bars depict the rainy months of April-September in Cox's Bazar.

As depicted in the Figure 1 graph, the ARI cases vary among the weeks since 2018, with the range of the percentage of ARI cases from 0.01% to 2.7%. The ARI cases consistently fall between the 1% and 1.5% range. Overall, across the board, the cases are rather consistent among the weeks from 2018-2020. With the addition of shaded gray bars, depicting the rainy seasons in Cox's Bazar, there does not appear to be significant seasonality shown. The ARI cases are rather consistent among the rainy and non rainy months.

From 2018, where more solid fuels such as firewood and animal dung were used, the lowest percentage of fatalities associated with acute respiratory infections was observed, as seen in Figure 1. This is an unexpected finding because it is known that biomass use results in increased air pollution, and more particulate matter that can enter and colonize the lungs. The occurrences of acute respiratory infections were approximately the same for 2019 and 2020, where the fuel sources transitioned from solid fuels to greener ones, such as cooking gas cylinders, as depicted in Figure 2.

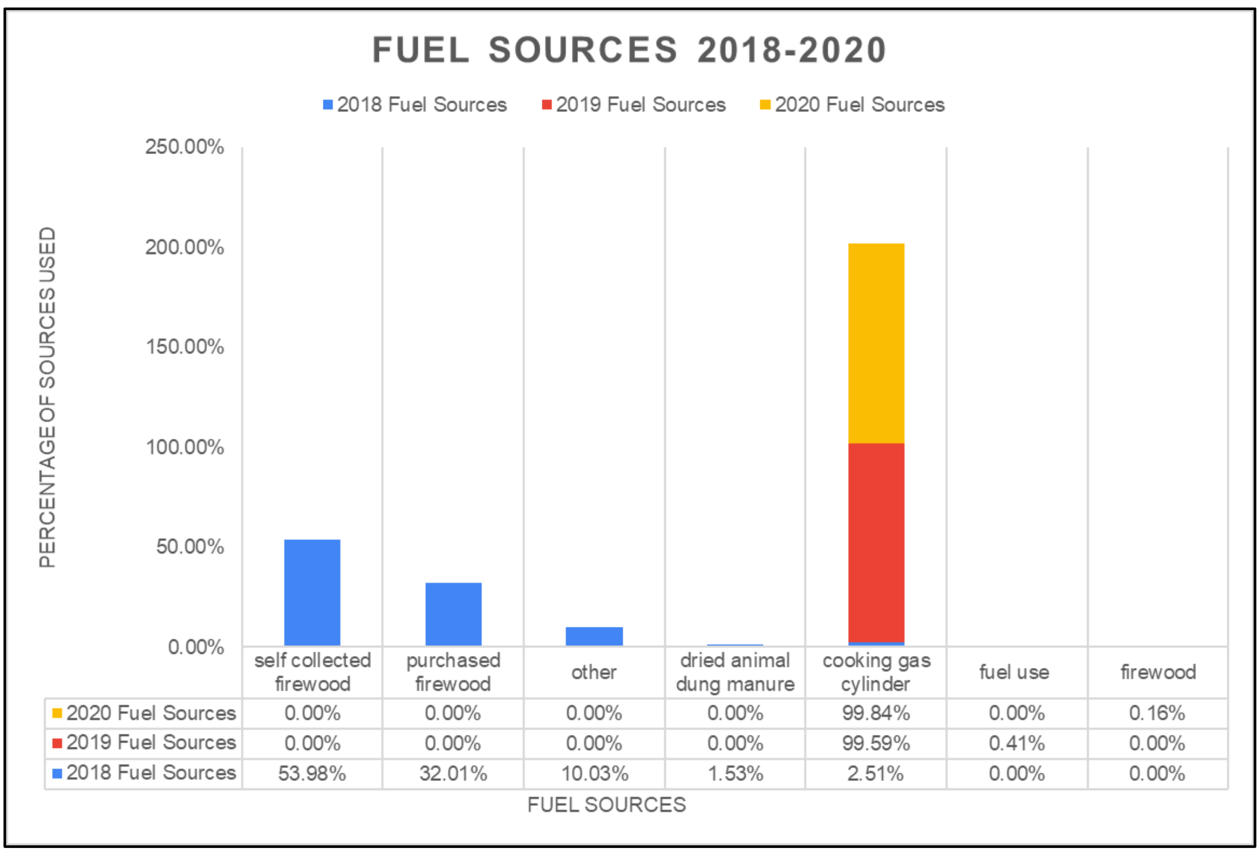


Figure 2. A stacked bar graph depicting the percentage of each fuel source used divided by the number of people surveyed from the Needs and Population site assessments, accessed from the humanitarian data exchange. The fuel sources were coded from 0-6 for the years 2018, 2019 and 2020, for ease of tracking, In order, the fuel sources were: self collected firewood (0), purchased firewood (1), other (2), dried animal dung manure (3), cooking gas cylinder (4), fuel use (5), and firewood (6).

From Figure 2, it is visualized that the fuel sources for 2019 and 2020 overlap for all the sources coded. For both years, the least fuel sources used were self-collected firewood, purchased firewood, other, dried animal dung manure, cooking gas cylinder, fuel use and firewood. The most used fuel source for those years was source 4, which is associated with cooking gas cylinder use. The fuel sources for 2018 were however different, with the least used sources being dried animal dung manure, cooking gas cylinders, fuel use, and firewood. The most used fuel source was source self-collected firewood, and shortly behind are sources purchased firewood and others.

As depicted in Figure 2, there was no shift from 2019-2020 in the differences among the fuel sources, and the number of fatalities associated with acute respiratory infections were comparable as well. This does not correlate with what is currently being stated in the literature. It is expected the shift from solid fuels to greener fuels should decrease the acute respiratory infection rates in the camp. In an article written on whether biomass or liquid petroleum gas was better for cooking, it was stated that there is an importance on the efficiency of the stoves as well (Yamamoto et al. 2009). When the stoves are cheaper, and inefficient at processing the solid fuel sources, more pollution is created both inside and outside (Yamamoto et al. 2009). In the same article, it is also argued that due to the limited resources available in low-income countries, use of fuel sources such as liquid petroleum gas (LPG), can use less amount of fuel than biomass sources, to cook the same meal (Yamamoto et al. 2009). Therefore, if theoretically less fuel can be used for the same process, it should be causing less pollution indoors and outdoors, conversely lowering the occurrences of acute respiratory infections in the population. There are some theories about why this is not being seen in the camp. One possible theory is that there is a potential lack of education on the proper use, sanitary practices, and cleaning of the cooking gas cylinders. Without these measures being taken, there is a potential for more particulate matter to be released, also leading to air pollution. Another possible theory for the improvement of the camp is surrounding industrialization. The addition of more equipment, and more technological advances could improve the conditions of the refugee camp and sanitation. If there were more resources available to clean the cooking stoves in a more uniform manner, there could be a change noticed in the ARIs in the camp.

With solid fuels, and the overall poor air quality of the area, it is important to note the effects of air particulate matter with diameters of 2.5 micrometers and 10 micrometers. The overall air quality in Bangladesh is continuously ranked the number one polluted country in the world (IQ Air, n.d). This has been consistent since about 2018. The WHO recommends safe levels of $PM_{2.5}$ are 5 micrograms per microliter (WHO, n.d). In 2019, in Bangladesh, the levels were measured approximately 83.30 micrograms per microliter, which is over 16 times higher than the recommendation from the WHO (IQ Air, n.d). Of the highest ranked cities in Bangladesh, Chittagong, which is in close proximity to Cox's Bazar, is consistently ranked among the highest polluted areas, just behind Dhaka, the capital (IQ Air, n.d). Scientifically, air particulate matter of a diameter of 2.5 micrograms per microliter or less, comes from organic compounds, combustion, metals, etc. These small particles can access the alveoli, which are air-filled sacs present in the respiratory system. Alveoli are of significant importance in gas exchange, and this process can be disrupted with the presence of small particles. Additionally, the small particles have the ability to come in contact with the ciliated bronchoalveolar cells, protruding into the lungs, causing a high risk of acute respiratory infections. On the other hand, larger particles with a diameter of 10 micrometers per microliter or less, can get trapped in the nasal passages, making it harder to breathe, potentially leading to infection or dyspnea. Not having enough accurate air quality readings for the area is one of the major limitations of the study. If there was enough air quality data on the area, this could have been included as one of the covariates for the study. It is known the air quality is poor in the area of Bangladesh, but looking more specifically into how this quality changes throughout the year with the acute respiratory infection cases would have been beneficial. In areas with poor air quality, individuals should be wearing masks, and understanding how accessible these masks are to individuals in the refugee camps could have been incorporated into the study as well.

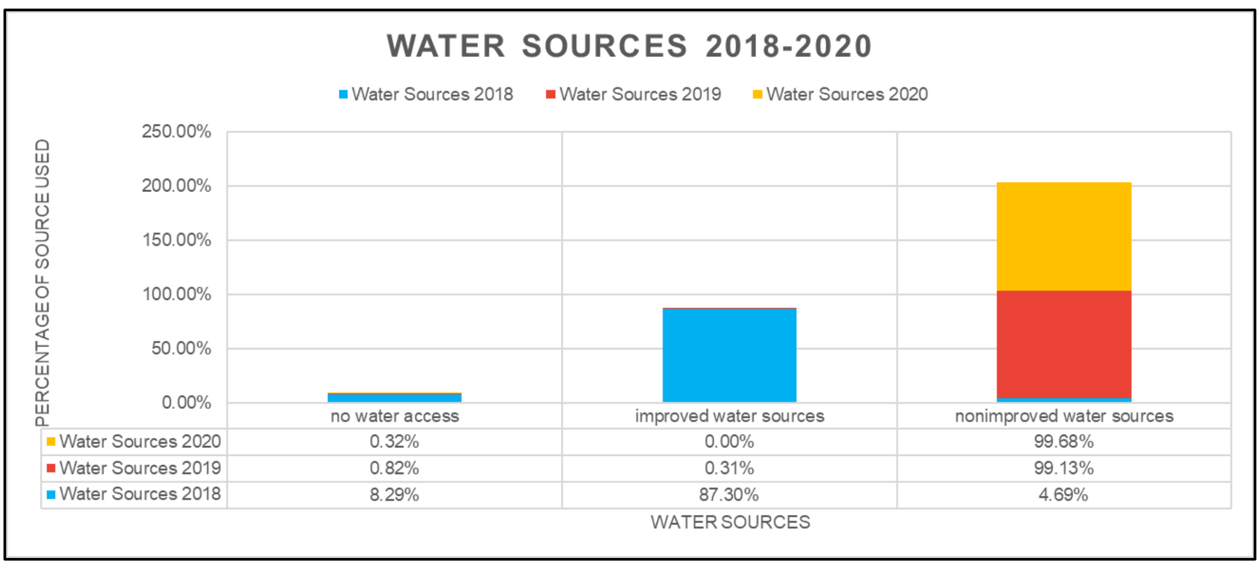


Figure 3. A stacked bar graph depicting the percentage of each water source used divided by those surveyed from the humanitarian data exchange for 2018, 2019 and 2020. In order, the water sources were: no water access, improved water access, and non-improved water access.

From Figure 3, the water sources for 2019 and 2020 overlap greatly. The fewest percentage of individuals in the camp had no water access or improved water access, coded by 0 and 1 respectively. For both years, the largest percentage of individuals had non improved water access, as coded by 2. For 2018, a few percent of individuals either had no water access or non-improved water access as coded by 0 and 2 respectively, with the highest percentage of individuals having improved water access, as coded by 1.

For both improved and unimproved water sources, it was shown that when there was more access to improved water sources, there were lower overall acute respiratory infection rates. In 2018, 0.91% of the population of the camp was impacted by acute respiratory infections. From the needs and population monitoring data, 87.3% of those surveyed had access to improved water sources, as depicted in Figure 3. In 2019 and 2020, there were higher acute respiratory infection rates, and lower improved water source rates, with higher non improved water sources, as depicted in Figures 1 and 3. This means that there is a potential correlation between water sources and acute respiratory infections. From 2018 to 2019 to 2020, there was almost a 0.4% increase in fatalities associated with acute respiratory infections. In a previous study conducted on potential drivers of acute respiratory infections in children under five in Ethiopia, it was found children who drank water from non-improved water sources were exponentially more likely to contract an acute respiratory infection than those who had access to improved water sources (Merera, 2021). This is potentially the result of the minerals, particles, and other materials which can be found in non-improved drinking water. Non improved water is unprotected from the elements and storms, which causes the movement of debris. It has also been previously stated that with improved water sources, there is the promotion of a healthy immune response due to the limited pathogens included in the drinking water (Swarthourt et al, 2020). Acute respiratory infections and diarrheal diseases seem to have a significant comorbidity, which may be a result of the pathogens found in the water and nutrient loss from the diarrheal diseases (Swarthort et al, 2020). If more time was allotted for the study, it would have been interesting to look into the comorbidity between diarrheal diseases and acute respiratory infections in Cox's Bazar. Both of these conditions account for a significant death toll in the refugee camp, and an investigation in the camp specifically could be important in the creation of public health measures.

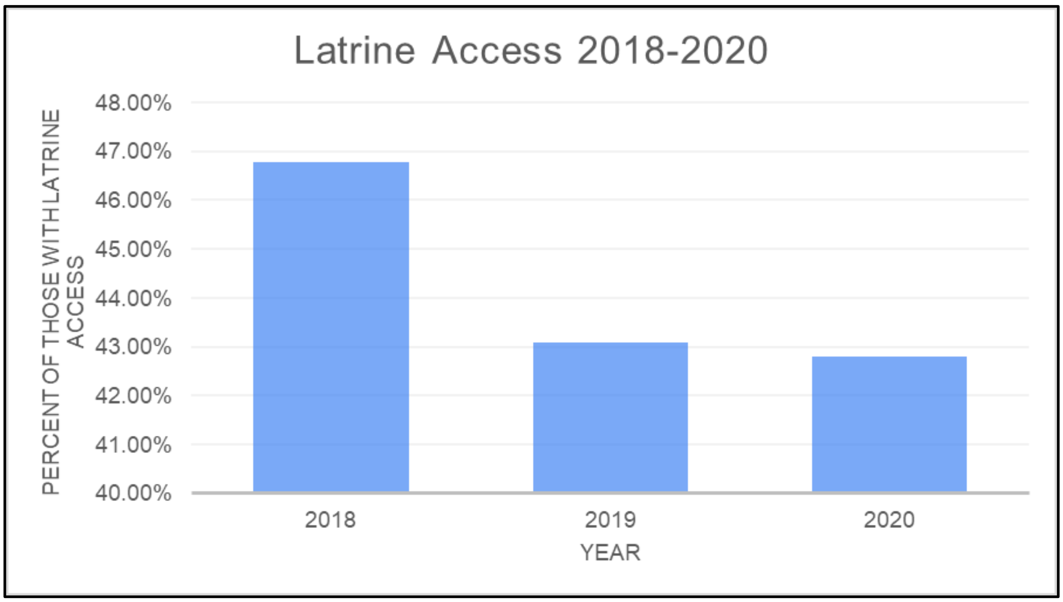


Figure 4. A bar graph depicting the percentage of those with latrine access from 2018-2020, of those surveyed from the humanitarian data exchange. The x axis shows the years 2018-2020, and the y axis shows the percentage of those with latrine access from the survey.

For Figure 4, 2019 and 2020 overlap, with the greatest number of individuals having no access to latrines, as coded by 0, and less having access to latrines, as coded by 1. The pattern is the same for 2018, with more individuals having no access to latrines than those with access; however, this difference is more evenly split between the conditions than it is for 2019 and 2020.

With the comorbidity of acute respiratory infections and diarrheal disease in mind, latrine access was investigated as one of the covariates for the study. Diarrheal diseases are highly infectious, and with use of shared latrines, there is a high risk of exposure. For latrine access, in relation to the acute respiratory infections, there was not a significant relationship found. For all years, there was around a 50/50 split between those that have access to latrines and those that do not. Although there was a close split among those surveyed, there were slightly more individuals who did not have latrine access for all three years. I was unable to show that there was a potential correlation between acute respiratory illnesses and whether there was access to latrines. This result differs from a study also conducted in Bangladesh, where there was a focus on intestinal parasites, and if taking these drugs reduced the potential to contract an acute respiratory infection (Imran et. al, 2019). There is a helminth parasite that can be spread by feces in various locations (latrines, soil) named *Ascaris lumbricoides* (Imran et. al, 2019). When the larvae of this helminth enters the body, they can colonize in the lungs, leading to Loeffler's Syndrome, persisting as Ascaris pneumonia, an acute respiratory infection (Imran et. al, 2019). Therefore, as more sanitation and hygienic measures are needed in the camp, this parasite has potential to persist in the environment, and spread to other individuals. In another study conducted, it also depicted whether individuals shared latrines with other households (Swarthourt et al, 2020). It was found there was an increased likelihood for individuals to become infected with an acute respiratory infection, such as influenza, with shared latrines (Swarthourt et al, 2020). For the latrine access data, there were limitations as not all of the individuals in the camp were surveyed, but a rather small portion. If more people had been surveyed, there may have been more varied results. With the investigation of the literature regarding latrine access, it can also be noted as another limitation for the WHO data for acute respiratory infections, as it does not define what diseases cause the most fatalities. Instead, the data is just one group, when having subsets would be helpful in the creation of public health guidelines and sanitation measures. If it was shown that diseases coming from parasites spread by fecal matter lead to acute respiratory infections and deaths for many in the camp, stricter guidelines could be created. Overall, based on the literature, acute respiratory infections could potentially be caused by latrine access, but the data is not statistically significant, and this conclusion was unable to be made in Cox's Bazar.

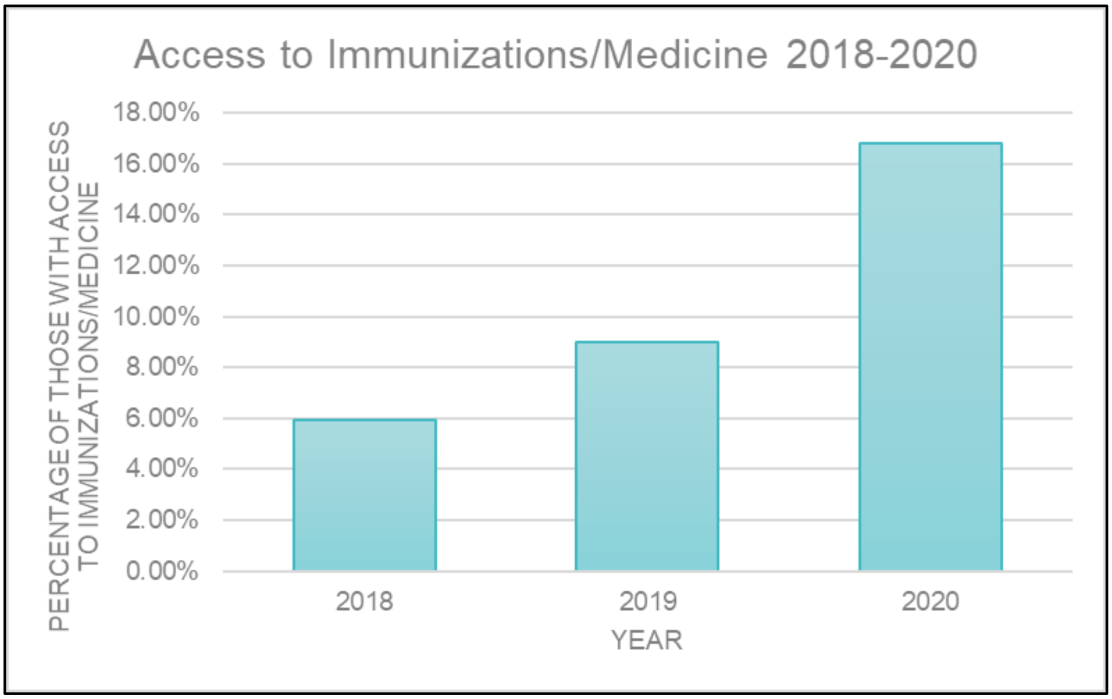


Figure 5. A bar graph depicting the percentage of those with access to immunizations/medicine from 2018-2020, among those surveyed from the humanitarian data exchange. The x axis shows the years 2018-2020, and the y axis shows the percentages of those surveyed with access to immunizations/medicine.

For Figure 5, there are differences in the years between the percentages of each condition, but the same pattern shows that more people do not have access to immunizations/medicine than those that do. For 2018, 94.06% of the individuals surveyed did not have access to immunizations, and 5.94% did have access. For 2019, 91.03% of the individuals did not have access to immunizations, while 8.97% did. Lastly, for 2020, 83.19% of the individuals did not have access to immunizations/medicine, while 16.81% did have access.

Along with latrine access, it is important to determine if access to immunizations/medicine has an impact on the occurrences of acute respiratory infections. In this study, it was found that for all three of the years studied, most of those surveyed did not have access to immunizations/medicine, so a potential correlation between the two was unable to be made. In a study conducted in India, it was found that with the implementation of an immunization schedule, there was a reduction of fatalities associated with acute respiratory infections (Selvaraj et al, 2014). It is believed an immunization schedule can be helpful to those in Cox's Bazar for many illnesses in the camp, but expense is a concern, as well as differences in beliefs among individuals on the topic (Selvaraj et al, 2014). Vaccinations also have the ability to build up the immune system with pre-exposure to certain pathogens at a manageable level. Even if the pathogen acquired is not the same as the one vaccinated against, if the mechanism is similar, the immune system will remember how to properly expel it. If there is no access to medication to treat the acute respiratory infection, it is more likely to further colonize in the lungs, continue to progress, and may even lead to death. Immunization does not necessarily cure the illness, but can lessen the severity of the symptoms, and therefore, fatalities. It is also of importance to note that in low-income countries, vaccines have a lower efficacy, which can contribute to no correlation found. In one of the studies discussed above, when medications were prescribed for *Ascaris lumbricoides* in Bangladesh, there was not a proven association with acute respiratory infections (Imran et. al, 2019). There were many other factors improved such as the reduction of open air defecation, and improved sanitation, which may have resulted in a decrease of the prevalence of the helminth infection and acute respiratory infection (Imran et. al, 2019).

Undoubtedly, there are many factors that can be combined in the improvement of acute respiratory infections in low-income countries.

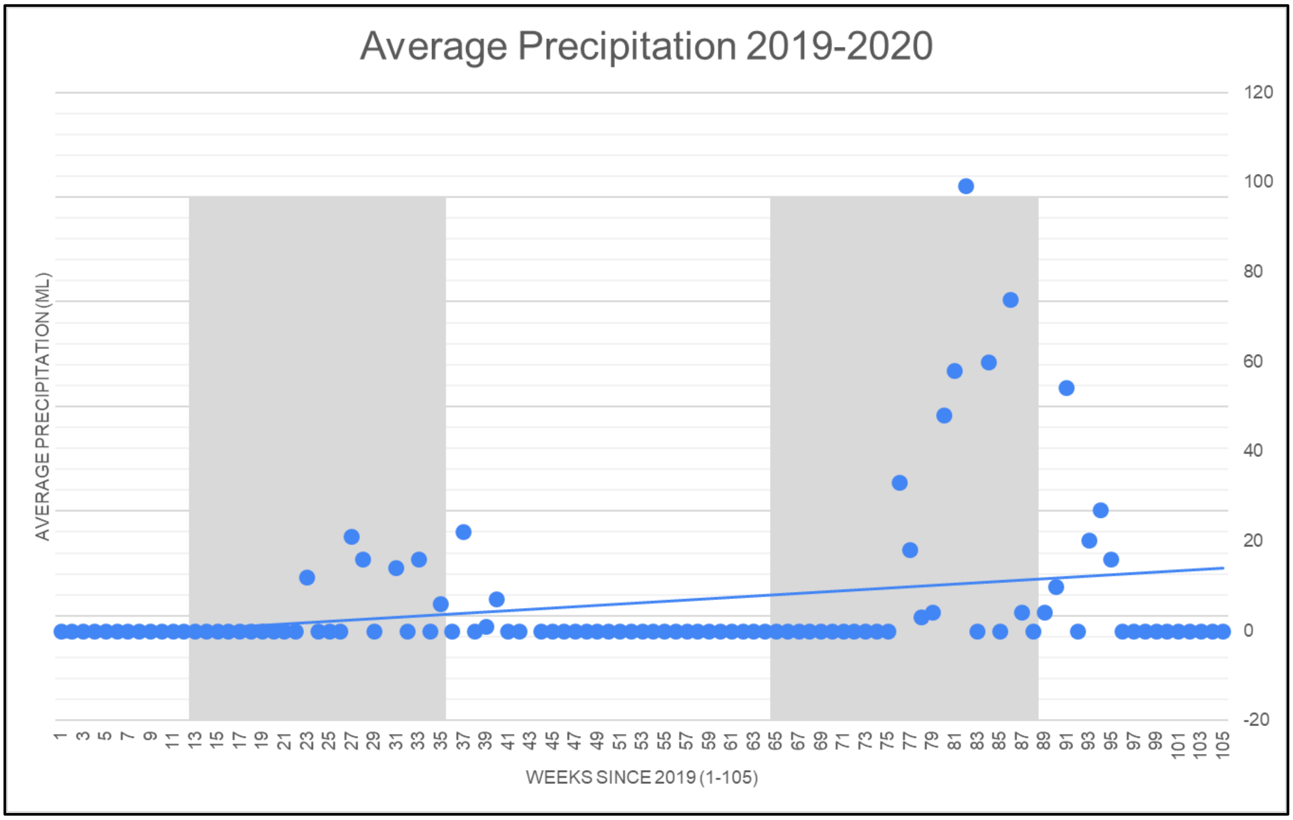


Figure 6. The average precipitation from weeks 1-105 for the years 2019 and 2020 with use of GIS. The line of best fit shows the trend of data.

For Figure 6, there was no precipitation data collected from the year 2018 by the Gleason Research Group. It can be seen there were higher average precipitation rates in 2020, then there were in 2019. In both 2019 and 2020, there were peaks in the average precipitation between weeks 21 and week 40. There was a noted upward trend from 2019-2020 in terms of the average precipitation in the camp.

It makes sense that the highest average precipitation occurred in the weeks associated with the rainiest months from April - September in Cox's Bazar (World Bank). With the higher average precipitation, comes the probability for mudslides and flooding, with rising water levels (Kamal et. al, 2022). This has the ability to cause more people to flee their homes and relocate to safer areas causing overcrowding in certain areas of the camp. This can lead to the spreading of more diseases in a shorter time period due to the close proximity in which they are to one another. Acute respiratory infections, more likely with upper respiratory tract than lower, have the ability to spread in these conditions. These infections can spread by sneezing, breathing, and coughing, and have a higher likelihood of spreading to other individuals.

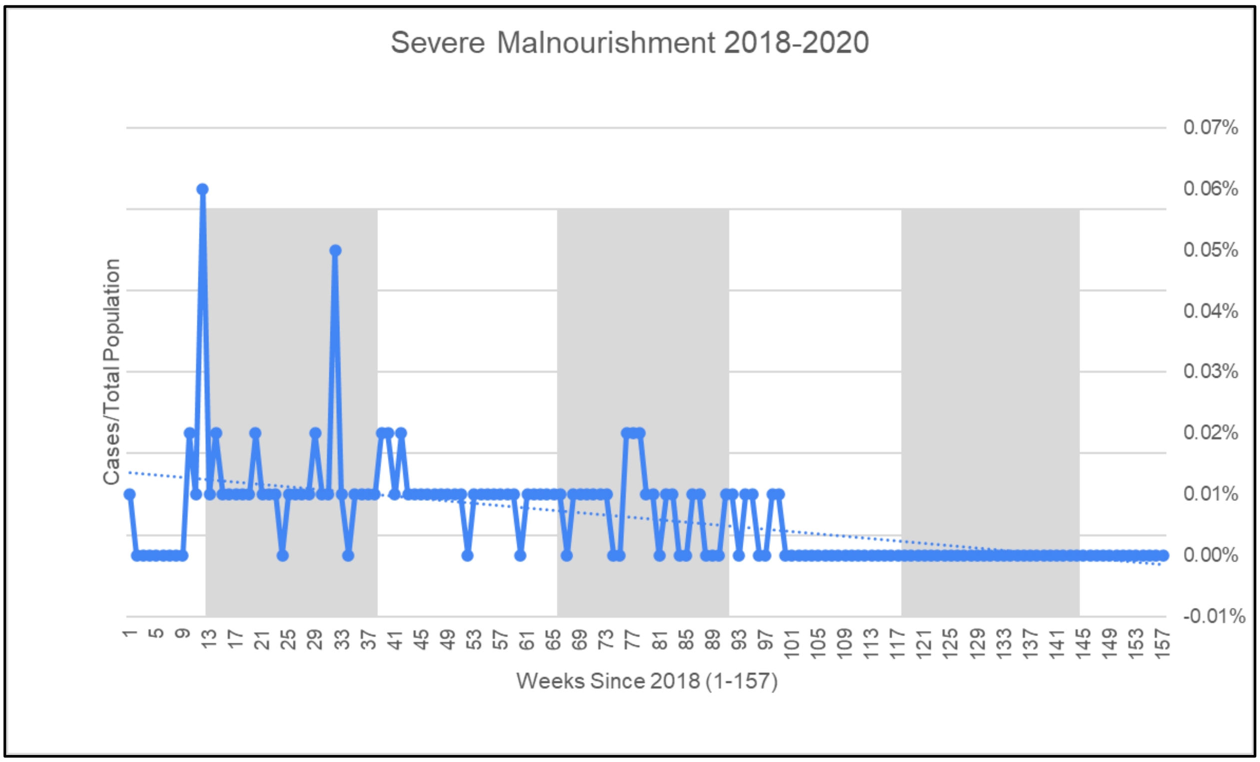


Figure 7. The cases of those severely malnourished over the total population of the refugee camp from 2018-2020. These cases were taken from the WHO, and associated with fatalities from the camp. The weeks 1 - 147, two were tracked. The shaded gray bars depict the rainy months of April - September in Cox's Bazar.

For Figure 7, it can be seen that the highest percentage of those severely nourished from the total population of the refugee camp was in 2018, with a percentage of 0.06%. This year also has the highest average of cases at 0.01%. In 2019, there were less cases of severely malnourished individuals, with the highest percentage occurring at around 0.02%, and an overall average of the 52 weeks was also 0.01%. For 2020, there was an average of 0.0% fatalities from severe malnourishment in the camp. With the shaded bars indicating the rainy months, there also appears to be no seasonality shown with severe malnourishment cases.

Regression Models

Covariate	Estimate	P Value
Severe Malnourishment	79.42	0.000004***
Rainfall	-12	0.624
Total Population	-0.000603	0.964

Model 1: Output from the linear regression Model 1 for each of the variables that were kept track of weekly. The estimate and the p-value are shown. The asterisk (*) indicates statistical significance.

From Model 1, the linear regression where time was not incorporated, the results were the following. Severe malnourishment was the only statistically significant variable (p>>0.001). The estimate for severe malnourishment was 79. This means that for every one person affected with severe malnourishment, it is associated with a 79 increase in ARI cases, adjusting for the total population and rainfall. The rainfall had an estimate of -12 and p= 0.624. For the total population, there was an estimate of -0.0006 and p=0.964. Rainfall and total population were not found to be statistically significant based on these values, which can be demonstrated by the high p values calculated.

Covariate	Estimate	P Value
Severe Malnourishment	0.0038	0.00051***
Rainfall	0.0023	0.2
Total Population	-0.000012	0.15

Model 2: Output from the linear regression Model 2 for each of the variables that were kept track of weekly. The estimate and the p-value are shown. The asterisk (*) indicates statistical significance.

For Model 2, the linear regression where time was incorporated, the results were the following. Severe malnourishment was also the only statistically significant variable found, with an estimate of 0.0038 and p=0.000508. This means that for every one person affected by malnourishment, it is associated with a 0.0038 increase in ARI cases. For rainfall, there was an estimate of 0.0023 and p= 0.204. The total population had an estimate of -0.0001 and p=0.149. Rainfall and total population were again not found to be statistically significant based on these values, which can be demonstrated by the high p values calculated.

Through linear regression Models 1 and 2, it was found that only severe malnourishment had a statistically significant association with acute respiratory infections in Cox's Bazar. Both rainfall and the total population of the camp did not have a statically significant impact, as shown through the analysis of the p-values gathered from the regressions. It is consistent with other studies where severe malnourishment has been shown to have a profound impact on the occurrences of many diseases, including acute respiratory infections. In a study also conducted in Bangladesh, it was found that malnourishment was correlated with acute respiratory infections, as people who were malnourished were more likely to contract an acute respiratory infection, than those who received adequate nutrition (Imran et. al, 2019). In another study conducted in New Delhi, India, it was also found that malnourishment played a significant role in the acute respiratory infection rates (Boor et. al, 2001). Rainfall has been shown in previous studies to increase acute respiratory infections. This is included in the seasonality that occurs in Bangladesh with the three main seasons experienced (Rahman et al, 2015). However, even when time was incorporated into the linear regression model, there was no statistical significance found between rainfall and acute respiratory infections, which differed from other studies investigated. In another study conducted in Bogota, Columbia, it was found that seasonality increased the viral circulation, also leading to an increase in acute respiratory infections (Evelyn et al, 2019). It is also known that with rainfall, more people are apt to move indoors, creating overcrowding in certain areas. This has the potential to further spread respiratory infections.

Overall, there are many limitations from this research study. The first major one includes the data sources which could be used in the project. The data availability from this camp is general is largely driven by political factors (ACAPS, 2022). Before any data collection can begin in the camp, the Bangladeshi Government Office of the Refugee Relief and Repatriation Commissioner must know all of the details such as method of data collection, budget, and give time constraints on how long they can visit (ACAPS, 2022). After the data has been collected, the findings are presented, and must be approved before further use (ACAPS, 2022). There are many protections in place due to the vulnerable nature of some of the data desired.

The Needs and Population Monitoring from the Humanitarian Data Exchange was very unorganized and varied greatly between the different site assessments analyzed. This data source also limited the years that could be studied due to disorganization and inconsistencies in the data posted. There were also only a small portion of residents in the camp surveyed for each of these site assessments. This made it difficult to pick covariates as they had to have been surveyed for all of the years to be further analyzed. The WHO data was also rather unorganized, and some of the weeks did not have data for acute respiratory infections or severe malnourishment.

A covariate ‘wish list’ in this study can be described as the ideal covariates that would have had access to data for. These covariates from the ‘wish list’ were identified through the literature from previous studies. From the covariate ‘wish list’, there were factors mentioned such as: gender, age of those affected, average family size, whether there is smoking in the house, ventilation, whether children are held while cooking, and more air quality data. These factors would have added more humanistic factors, and the ways of life of the people in the camp. For many, there has not been an opportunity to see the camp in person, and these additional covariates could fill in those gaps. It is of importance to have this data accessible, especially with many conducting this research outside of Cox’s Bazar.

Factors such as ventilation, and whether children were held or standing during cooking could have been crucial for the study. In a study conducted in Ethiopia, some of the covariates used were the following: windows in the house, whether the child is being held/carried on the back while the mother is cooking, and tobacco smoke frequency (Alemayehu, 2014). Correlations of these covariates could have shown an increased chance of acquiring an acute respiratory infection, but no data sources with this information could be found. If the child is being held near the cooking fuel source while the mother cooks, there is the potential to increase the level of exposure to the source (Alemayehu, 2014). This is due to the fact that when the mother holds the child, this brings them closer to the source itself, which can cause the entry of air particulate matter (from solid fuels) into the lungs. These particles can travel deep into the lungs, and eventually lead to conditions such as respiratory infections, coughing, and shortness of breath. This could explain the statistics associated with fatalities from acute respiratory infections in children five and younger as children do not have a fully developed respiratory system, which results in a vulnerability to these small air particles. Their airways and lungs are still developing along with immune defenses that would normally increase mucus production to push the pathogen out of the body. From this same study, there is also importance in data if the those affected come from a smoking household (Alemayehu, 2014). This covariate would have been helpful to include as this would compromise gas exchange in the respiratory system, and the lungs. Even secondhand smoke can have a similar effect on individuals. With the lungs being compromised, one's breathing and gas exchange would be severely impaired, increasing the possibility of contracting an ARI.

The gender of those with acute respiratory infections in Cox's Bazar, would have also been rather interesting to include in my study. In a study conducted in India, one of the covariates investigated was gender (Mishra et. al, 2005). This would have been helpful to include, due to the gender differences of children playing an important role in the levels of pollutants they are exposed to, and care in general (Mishra et. al, 2005). However, this information was not accessible, and there was only access to the percentage of the population with deaths as a result of acute respiratory infections.

The percentage of those successfully immunized was unable to be found, data from the survey instead had to be used that indicated whether households have access to immunizations and medicine. The data from the WHO also did not have specifications for which acute respiratory infections were prevalent in the camp, which would have been helpful for further public health determinants. This created a few gaps in research for the experiment. It is of the utmost importance for this data to be more organized, for more efficient analyses. As a result of these factors, there were limitations in the variables that could be used. Many covariates from previous studies conducted on acute respiratory infections such as parental education status, house type, religion, and many more, were unable to be included, due to lack of data. There was also a limitation with the inability to use GIS techniques, where there was access to only two years weekly of rainfall data instead of three. This is not critical, but more significance may have been noted with another years' worth of data. Only having the three years, also limited in the tests that could be completed for the variables there were only yearly averages. There were not enough years to complete a regression. This explains why graphs were used for this analysis.

It is important to note this study and its findings are not an ecological fallacy. An ecological fallacy can be defined when two topics are inaccurately associated through statistical inferences (Brittanicia). This phenomenon has the tendency to state the actions of a group level, and undermines the importance of the individual. For example, an ecological fallacy would be associating the increase in pirates to global warming because the two happened at the same time and must somehow be related. In this study, it references the correlation between covariates and acute respiratory infections, not causation. Based on the data available, which is both at household and population levels, there was a goal to determine factors that had the potential to increase acute respiratory infections in Cox's Bazar.

For future research on this topic, it would be significant to investigate more covariates and their impact on acute respiratory infections in Cox's Bazar specifically. Acute respiratory infections have been a consistent leading cause of death in the camp, and it is important to determine more potential drivers. More research should also be conducted on the comorbidity between diarrheal diseases and acute respiratory infections in the camp. There could also be a more long-term study with research from 2017-2022 and further to retrieve more data and provide a bigger picture of the issues within the camp.

This research is significant as it exposes many of the gaps created by the data sources available for analysis of Cox's Bazar. More access to immunizations/medicines, latrines, food and supplements, and education all play a crucial role in decreasing acute respiratory infections in the camp. More variables need to be investigated and added to these data sources to allow improved education of public health officials surrounding the crisis at Cox's Bazar. Furthermore, this research can also be applied to other countries and crises. There are many other refugee camps in which ARIs are the number one leading cause of death. These include camps in Thailand, Somalia, Sudan, and Honduras (CDC, 2022). This is not the only refugee camp in the world, and many are overcrowded and unsupplied, similarly to Cox's Bazar. There are also environmental, political, and economic concerns that lead to health crises in other refugee camps.

Conclusion

The occurrence of ARIs has been known as the leading cause of death in Cox's Bazar (WHO, n.d). Therefore, it was of importance to determine potential drivers of the ARIs in the camp. Through data collection, it was found that as there was a shift from solid biomass fuels towards cooking gas cylinders and there were increased acute respiratory infection fatalities. This shift was made possible with the introduction of cooking gas cylinders in the camp, in the attempt to reduce environmental stress (IOM, 2018). The environmental stress in the camp came from the deforestation associated with the influx of refugees (IOM, 2018). The trees had been cut down for fuel and to make room for homes to be built. Before the Rohingya crisis, the land housed a lot of different species of trees and wildlife (IOM, 2018). With the rate at which the forest was cleared during the influx, there were few to no trees left in the camp (IOM, 2018). In addition, there have been positive correlations shown with the use of cooking gas cylinders in place of biomass fuels in terms of air pollution (Yamamoto et al. 2009). Cooking gas cylinders are supposedly more efficient than biomass fuels, reducing cooking time, and therefore impacting air pollution (Yamamoto et al. 2009).

Additionally, there was a correlation found between acute respiratory infections and water access, as well as severe malnourishment in the camp. For those that had water access in 2019 and 2020, there was mainly access to non-improved water sources as depicted in figure 3. These non-improved sources are unprotected and are potentially looted with minerals and debris. With exposure to these toxic chemicals, it was shown in other areas such as Ethiopia to have an association with increased ARI occurrences (Merera, 2021). In general, there are proven benefits to drinking from improved water sources, in relation to the immune system (Swarthourt et al, 2020). However, due to the limited amount of data collected from the Needs and Population Monitoring, it was uncertain how strong of a correlation there was between water access and ARIs. On the other hand, with the weekly data collected from the WHO for severe malnourishment, and two linear regression models run, there was certainty in the correlation found between severe malnourishment and ARIs. In various other areas, there are similar correlations between severe malnourishment and diseases, including ARIs. For instance, in a study conducted in New Delhi, India, it was that those who did not receive adequate nutrition were more vulnerable to ARIs (Boor et. al, 2001).

Undoubtedly, there are many measures that need to be taken in the study of Cox's Bazar for the future. The data itself is highly politicized, narrowing what variables are able to be used, and collected (ACAPS, 2022). The data is also not uniform and rather unorganized, causing difficulty in the study of the camp, and the individuals. Many are unable to travel to Cox's Bazar and other refugee camps, which solidifies the significance of the data collection in the camp. There are also many more refugee camps where ARIs are the leading cause of death such as:

Thailand, Somalia, Sudan, and Honduras (CDC, 2022). With the conduction of research in one of these camps on the potential drivers of ARIs, there can be alterations in many policies in all the camps that have similar conditions, and the same leading cause of death.

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