Distribution Agreement

Signature:

__________________________ _________________

Shazneen Damani Date

Nasal Swabs or Wastewater Swabs? Comparing the Costs of Two Approaches for SARS-CoV-2 Surveillance in Atlanta Public Schools

By

Shazneen Damani
MPH

Hubert Department of Global Health

Christine L. Moe, PhD
Committee Chair

Sarah Durry
Committee Member

Stephen Hilton
Committee Member

Nasal Swabs or Wastewater Swabs? Comparing the Costs of Two Approaches for SARS-CoV-2 Surveillance in Atlanta Public Schools

By

Shazneen Damani
Bachelor of Science
University of North Texas
2019

Thesis Committee Chair: Christine L. Moe

An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Global Health
2023

Abstract

Nasal Swabs or Wastewater Swabs? Comparing the Costs of Two Approaches for SARS-CoV-2 Surveillance in Atlanta Public Schools

By Shazneen Damani

In the spring of 2020, approximately 55 million school-aged children in the United States were confined to their homes (Bureau, n.d.). Since then, it is estimated that more than 13.9 million children under 18 years of age have been infected with SARS-CoV-2 (Michaud & Dietz, 2023). Wastewater-based epidemiology (WBE), is surveillance approach that has gained attention in recent months and has been utilized at colleges and universities to monitor the prevalence and spread of SARS-CoV-2 across the campuses (Harris-Lovett et al., 2021). However, there are limited studies that have examined the application and effectiveness of WBE in K-12 public schools. Our study conducted a pilot study to examine two surveillance approaches in ten schools and their implementation costs over a span of two academic years. The goal of the study was to collect data on the costs of rapid antigen diagnostic testing in Atlanta Public Schools and compare that to the cost of wastewater monitoring. This study utilized an activity-based cost (ABC) analysis and sensitivity analysis to compare the costs associated with each of the two surveillance approaches. Our findings indicate that the cost of implementing rapid antigen diagnostic testing in Atlanta Public School was 69 times higher than the cost of wastewater monitoring.

Nasal Swabs or Wastewater Swabs? Comparing the Costs of Two Approaches for SARS-CoV-2 Surveillance in Atlanta Public Schools

By

Shazneen Damani
Bachelor of Science
University of North Texas
2019

Thesis Committee Chair: Christine L. Moe, PhD

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Global Health
2023

Acknowledgements

It is my great pleasure to express my heartfelt appreciation and gratitude to the following individuals who have provided me with immense support, encouragement, and guidance during my thesis-writing process.

First and foremost, I would like to thank my incredible committee members Sarah and Stephen at The Center for Global Safe WASH. They provided me with an incredible opportunity to engage with *the Dissemination and Translation of Wastewater-Based Surveillance for COVID-19 to Support Public Health Response in Atlanta Communities – Reaching the Last Mile* project. I will be forever grateful for their mentorship and advice, which challenged me to think critically about the reality of working with stakeholders in K-12 communities, data analysis, and the future of surveillance research.

And another special shout out to Stephen who listened to details of my data analysis plan at all hours of the day and never failed to offer sage tips and advice for conquering R.

I am also immensely grateful to my thesis advisor and chair, Dr. Christine Moe. Her patience and sincere feedback allowed me to gain a new perspective on my work. Through her guidance, she embedded in me crucial lessons and insight for future WASH work.

I would like to extend a special thank you to Valencia Beckley Hildreth, Ph.D., RN, Director of Health Services, and Juliana Prieto, MPH, District Epidemiologist, who are part of The APS Health Services Department. The information provided by Dr. Hildreth and Juliana was instrumental in shaping my thesis process.

To all those in the Moe Research Lab, who dedicated tremendous time and effort to collect sampling, processing results, and generating amazing work, I am sincerely thankful.

Finally, I am eternally grateful to my dear friends, and family who supported me with words of encouragement throughout this process. And, most importantly, I am immensely grateful to my mom and brother, Dinar and Shawyan, who filled me with inspiration and determination throughout this thesis process and my time at the Rollins School of Public Health.

Thank you all for being a part of my journey and for contributing to my success.

Table of Contents

Chapter 1. Literature review ________ *1*

1.1 Introduction and background on the SARS-CoV-2 Pandemic and the impact of the SARS-CoV-2 pandemic on children's health, well-being, and livelihoods in the U.S. ________ 1

1.2 Percentage of Georgia children infected with SARS-CoV-2 since March 2020 ________ 2

Figure 1 ________ 3

Figure 2 ________ 4

1.3 Highlight the importance of understanding the spread of SARS-CoV-2 in learning communities, specifically in public schools. ________ 4

1.4 Current problem of SARS-CoV-2 spread in public schools and relevance in understanding the costs associated with monitoring and preventing transmission in these communities. ________ 6

1.5 Existing studies on the costs of COVID diagnostic testing in schools and the financial impacts. 8

1.6 Wastewater-based monitoring initiatives that have been utilized to examine the spread of SARS-CoV-2 in universities and other settings. ________ 8

1.7 Lack of studies that have examined the relationship between costs associated with conducting wastewater epidemiology in public schools compared to diagnostic testing. ________ 10

1.8 Summarize the current problem of SARS-CoV-2 spread in public schools and the significance of the study in understanding the costs associated with monitoring and preventing transmission in these communities. ________ 11

Chapter 2. Introduction, Research Objectives, and Rationale ________ *11*

Chapter 3. Methods ________ *13*

3.1 Study Design and Sample Selection ________ 13

Figure 3 ________ 14

Table 1 ________ 15

Figure 4a ________ 15

Figure 4b ________ 16

3.2 Data Collection ________ 17

3.2.1 Wastewater Monitoring Costs ________ 17

Figure 5 ________ 18

Figure 6 ________ 18

Table 2 ________ 21

Table 3 ________ 21

3.2.2 Diagnostic Testing Costs ________ 22

3.2.3 Classification of surveillance costs ________ 22

Table 4a ________ 23

Table 4b ________ 24

3.3 Data Analysis: ________ 24

3.4 Mathematical ABC and sensitivity Analysis Model and Model Structure ________ 24

3.4.1 Activity Based Cost Analysis Model and Model Structure ________ 25

Table 6 ________ 27

Table 7 ________ 29

3.4.2.Sensitivity Analysis Model and Model Structure 30
Table 8 31
Table 9 31
Chapter 4 Results 32
4.1 ABC Model results 32
Figure 7 33
Figure 8 34
Figure 9 35
Table 11 36
Figure 10 36
Figure 11 38
Figure 12 39
Figure 14 41
Table 12 41
Figure 15 43
Figure 16 43
Figure 17 44
Figure 18 45
Table 13 46
4.2 Sensitivity Analysis 46
Figure 19 47
Figure 20 47
Chapter 5 Discussion and Recommendations 48
5.1 Overall comparison of results ABC 50
5.1.2 Overall comparison of results Sensitivity Analysis 51
5.2 Strengths of Wastewater Testing 51
5.3 Strengths of Diagnostic Surveillance 52
5.4 Limitations of these Surveillance Approaches 53
5.4.1 Wastewater Monitoring 53
5.4.2 Diagnostic Testing 53
5.5 Strengths of this study 54
5.6 Additional considerations 54
5.7 Limitations 55
Chapter 6 Conclusion 56
References 58

Chapter 1. Literature review

1.1 Introduction and background on the SARS-CoV-2 Pandemic and the impact of the SARS-CoV-2 pandemic on children's health, well-being, and livelihoods in the U.S.

On March 11, 2020, the World Health Organization (WHO) declared the start of the SARS-CoV-2 pandemic (CDC, 2023). Since then in the United States the SARS-CoV-2 pandemic has had a substantial impact on the education system and has affected students of all ages and backgrounds (Dong et al., 2020). In the spring of 2020, approximately 55 million school-aged children in the United States were confined to their homes (Bureau, n.d.). During that time period, the impact of how SARS-CoV-2 affected school-age children was unknown. As the SARS-CoV-2 pandemic progressed more data became available and it was understood that children could become infected with SARS-CoV-2 and transmit the virus to others (Study Sheds Light on SARS-CoV-2 Transmission in Homes with Kids, 2023). A report from the American Academy of Pediatrics found that from March 2020 to April 2023, more than 15 million children under the age of 18 had been infected with SARS-CoV-2 in the United States (*Children and COVID-19*, n.d.). Evidence from an extensive literature search found that from May 2020 to August 2020 in the United States showed that the monthly incidence of SARS-CoV-2 in individuals aged 0-19 years approximately tripled during this 4- month period (Boehmer et al., 2020). The rise in cases indicated a growing role of children and adolescents in transmitting SARS-CoV-2 within communities (Boehmer et al., 2020).

However, despite children exhibiting similar patterns in incidence of SARS-CoV-2, they have recorded lower rates of morbidity and mortality from SARS-CoV-2 compared to adults (Leidman et al., 2021). The underreporting of SARS-CoV-2 incidence in children is most likely attributed to children exhibiting lower testing volumes compared to adults during the early stages of the pandemic (Kliff & Sanger-Katz, 2020). However, even with lower testing rates, the positivity rate was higher among children compared to adults (Park et al., 2020). This could be attributed to the fact that testing in the early stages of the pandemic was mainly focused on people displaying severe symptoms, which neglected to account for asymptomatic manifestations in children (Poline et al., 2021) and (Wu et al., 2020).

1.2 Percentage of Georgia children infected with SARS-CoV-2 since March 2020

Throughout the course of the SARS-CoV-2 pandemic, the fluctuations in the number of cases in Fulton County, GA followed the trends seen in Georgia. On March 2, 2020, Fulton County reported its first confirmed case of SARS-CoV-2 (Gov. Kemp, Officials Confirm Two Cases of COVID-19 in Georgia, 2020). However, as time went on it was found that Fulton County had a lower incidence rate of SARS-CoV-2 cases per capita compared to the state (Georgia Coronavirus Map and Case Count - The New York Times, n.d.). The lower incidence of SARS-CoV-2 in Fulton County could be due to various factors such as population density, public health interventions, testing capacity, and access to testing (Wang et al., 2021). In Fulton County during the initial peak of the SARS-CoV-2 pandemic, the GADPH implemented free SARS-CoV-2 testing for all eligible residents and children of all ages to help mitigate SARS-CoV-2 infections (*Expanded Testing For COVID-19 In Georgia*, 2020). This could explain the lower incidence rate of SARS-CoV-2 in Fulton County.

According to a report from the American Academy of Pediatrics (AAP) in July 2022, Georgia ranked among the states with the lowest vaccination rates for SARS-CoV-2 in children and teenagers across the nation (Children and COVID-19 Vaccination Trends, n.d.). The Georgia Department of Public Health (GADPH) Vaccine Distribution Dashboard last updated in August 2022, displayed the following vaccination trends in Georgia for ages 0- 4 years 3.9%, 5-9 years

18.2%, 10-14 years 33.8%, and 15-19 years 44.1% of the population had one dose of the vaccine (*Covid-19 Vaccine Dashboard*, n.d.). In July of 2020, a report found that the percentage of children infected with SARS-CoV-2 tripled in Georgia from February 2020 to July 2020 (Eldridge, 2020). In August of 2021, children in the age group of 0 to 17 years accounted for an average of 18% of SARS-CoV-2 cases in Georgia (COVID-19 Cases Climb among Young People; Metro Atlanta Teen Shares Her Story, 2021). Additionally, according to recent estimates for the period of October 2022 to December 2022 shown in Figure 2 from CDC; it was estimated 96.6% children in Georgia who tested for SARS-CoV-2 had been infected with SARS-CoV-2 (CDC, 2020).

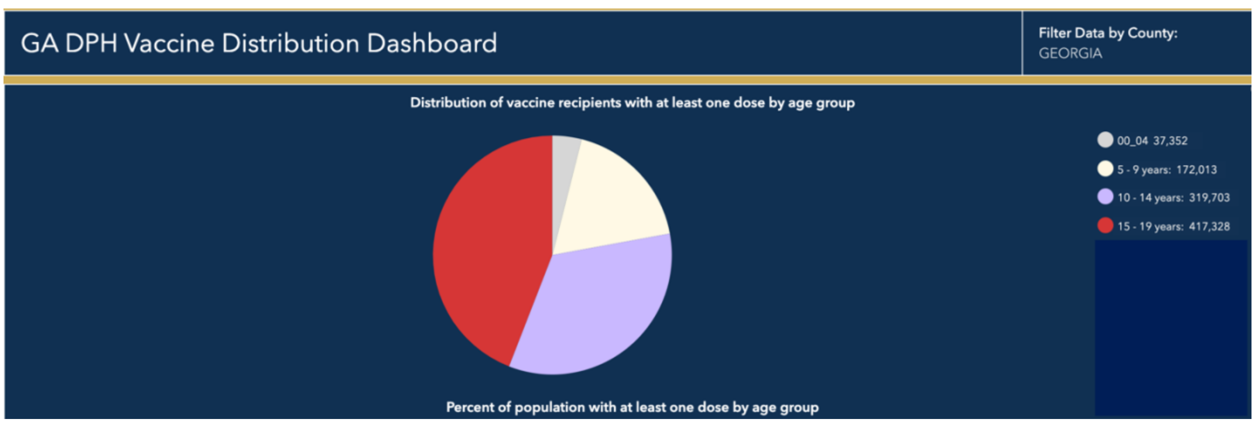

Figure 1 developed by GADPH(https://experience.arcgis.com/experience/3d8eea39f5c1443db1743a4cb8948a9c). This pie chart provides the distribution across ages 0 – 19 years old of those who have received at least one dose of a SARS-CoV-2 vaccine. Grey is ages 0- 4 years, Yellow is ages 5-9 years, Purple is ages 10-14 years, and Red is 15- 19 years.

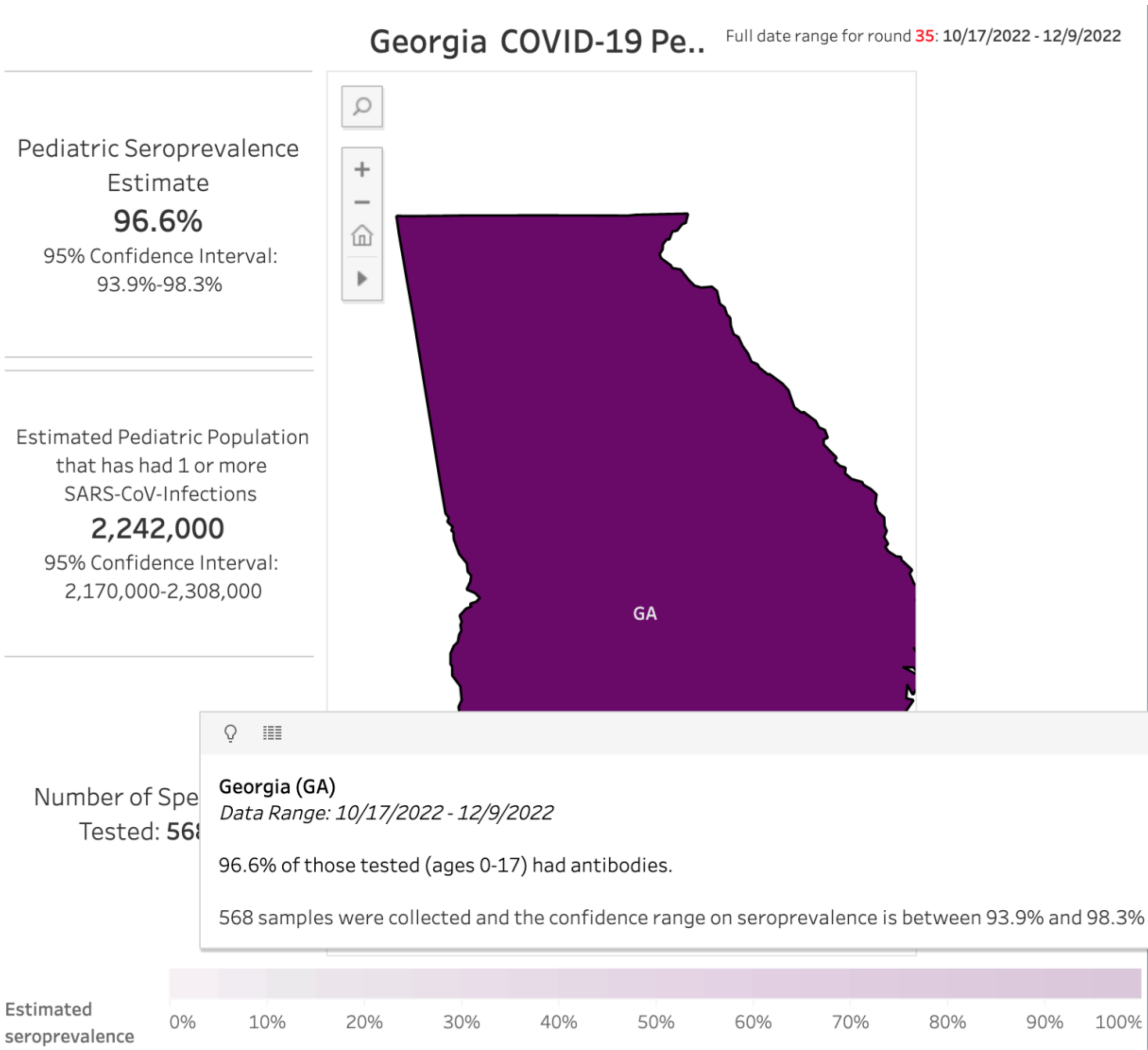

Figure 2 developed by the CDC (https://covid.cdc.gov/covid-data-tracker).This figure provides the pediatric seroprevalence estimate of all children aged 0-17 tested for SARS-CoV-2 antibodies in the state of Georgia for the time period October 2022- December 2022.

1.3 Highlight the importance of understanding the spread of SARS-CoV-2 in learning communities, specifically in public schools.

From March 2020 to December 2020 of the SARS-CoV-2 pandemic, the literature indicated a low number of children being tested for SARS-CoV-2 (Kliff & Sanger-Katz, 2020). The low number of children being tested may have caused the actual impact of the illness in ages 0-17 years to be underestimated (Updates + Alerts / Self-Report+ Weekly Case Report, n.d.). Even with the data indicating that children had lower recorded cases of SARS-CoV-2, research showed that as the overall incidence rate in the community rose, the incidence of SARS-CoV-2 also increased (Barrera et al., 2021).

As the SARS-CoV-2 pandemic evolves and progresses, it is important to keep facilitating research to gain an understanding of the impacts of SARS-CoV-2 and how the spread of the virus affects children (Barrera et al., 2021). From the data and literature currently available, we know that in comparison to adults, children who are exposed to SARS-CoV-2 are likely to experience a mild and short-lived illness and less likely to have severe symptoms that would lead to hospitalization, admission to intensive care, or death from SARS-CoV-2 (Gaythorpe et al., 2021). We also know that children play an important role in the transmission of respiratory viruses such as SARS-CoV-2 in learning communities (Donaldson et al., n.d.) and (Endo et al., 2021). Just like in any other congregate setting, schools have the potential to facilitate the spread of SARS-CoV-2 (Ismail et al., 2021). There are various factors that facilitate the transmission of SARS-CoV-2 in schools such as close contact in communal areas, improper ventilation, and fomites (Cai et al., 2020) and (Donaldson et al., n.d.). A study conducted to estimate the risk of SARS-CoV-2 spread in New York City public schools found that school buildings that were newly built compared to older buildings had a higher rate of transmission for SARS-CoV-2 (Pavilonis et al., 2021).

On March 26, 2020, Georgia's governor, Brian Kemp, declared an executive order to shut down all public schools until April 24, 2020; this executive order was later amended to extend school closures until the end of the 2020 school year (*Kemp Closes K-12 Public Schools Through April 24*, 2020). This executive order caused over a million students across the state to be confined to their homes and miss out on approximately nine weeks of in-person learning (Tabatadze & Chachkhiani, 2021). With the decision to shut schools down, it was evident that the SARS-CoV-2 pandemic had a substantial impact on school operations (Supporting Students During the COVID-19 Pandemic: Maximizing In-Person Learning and Implementing Effective Practices for Students in Quarantine and Isolation | U.S. Department of Education, n.d.). As time for the 2021 to 2022 school year approached many states such as Georgia decided to reopen and transition back into in person learning (*School Responses in Georgia to the Coronavirus (COVID-19) Pandemic*, n.d.) and (*K-12 State Reopening Plans · The Hunt Institute*, n.d.). Through an extensive literature review we found that the reopening of schools caused major disruptions in learning as well as increased the risk of transmission among individuals in learning communities (Supporting Students During the COVID-19 Pandemic: Maximizing In-Person Learning and Implementing Effective Practices for Students in Quarantine and Isolation | U.S. Department of Education, n.d.). A Burbio Dashboard, which aggregated school data from the initial reopening's on September 9, 2021, of schools in Georgia found there to be over 62 pandemic related disruptions (*School Opening Tracker*, n.d.). Through the literature review it is evident that the transition to in-person learning has had a profound impact on school operations, and that there is a need for research to explore, identify, and implement strategies that can detect and mitigate the spread of SARS-CoV-2 in schools.

1.4 Current problem of SARS-CoV-2 spread in public schools and relevance in understanding the costs associated with monitoring and preventing transmission in these communities.

Several studies have demonstrated that schools are a known high-risk setting for the transmission of respiratory infections such as SARS-CoV-2 (Flasche & Edmunds, 2021) and (Wang et al., 2014). The structured environment of schools offers a favorable setting for the implementation of key mitigation measures to curb the transmission of SARS-CoV-2. However, when the transition from remote to in-person learning happened many faculty and staff members did not feel safe enough to come back to the school environment (*Survey Shows Texas Educators Do Not Feel Safe at Schools, Overwhelmingly Support Mask Mandates and Rapid Testing for Covid-19*, 2022). Additionally, concerns were raised by staff members on the difficulty of maintaining masking measures (*Survey Shows Texas Educators Do Not Feel Safe at Schools, Overwhelmingly Support Mask Mandates and Rapid Testing for Covid-19*, 2022), which would make it challenging to control the spread of SARS-CoV-2. When states across the United States decided to reopen public schools and transition to in-person learning during the SARS-CoV-2 pandemic, it led to a surge in cases (Zimmerman et al., 2021) and (*Return to School Is Driving up Covid-19 Cases in Kids, but There Are More Tools to Keep Them Safe This Year | CNN*, n.d.). This surge in cases led to increased efforts to monitor and prevent transmission in schools (*Return to School Is Driving up Covid-19 Cases in Kids, but There Are More Tools to Keep Them Safe This Year | CNN*, n.d.). As schools determined the best monitoring and prevention methods for reducing SARS-CoV-2, there became an increasing need for information to better understand how SARS-CoV-2 surveillance measures affect school budgets and funding (Kennedy, 2020). Because schools are facing significant financial challenges because of the pandemic, understanding the costs associated with various approaches for monitoring disease spread is critical. Through our literature search, we found a study that anticipated that cases of SARS-CoV-2 to increase in schools during instances of high community transmission (Ismail et al., 2021). This was the case for a study conducted in North Carolina which investigated the impact of SARS-CoV-2 transmission in K-12 communities and found an increase in cases across the states communities as transition back to in person learning happened (Zimmerman et al., 2021).

1.5 Existing studies on the costs of COVID diagnostic testing in schools and the financial impacts.

Through an extensive literature review, we found that there were few studies that examined the impact of costs associated with diagnostic testing in public schools. However, we did find literature regarding the reopening of schools. With the onset of the SARS-CoV-2 pandemic and decision to reopen schools there was a need for monitoring and preventive measures to control the spread of disease. It was noted that during the initial start of the pandemic in March of 2020, that clinical diagnostic testing (CDT) was the gold standard for monitoring SARS-CoV-2 (Islam et al., 2022). The utilization of diagnostic testing in public schools such as Atlanta Public Schools (APS) was chosen as a monitoring measure (*Surveillance Testing in School / Surveillance Testing*, n.d.). Diagnostic testing is a method that involves collecting clinical specimens (usually nasal or nasopharyngeal swabs for COVID-19 Diagnosis) individuals and testing them for the presence of SARS-CoV-2 using polymerase chain reaction (PCR) or rapid antigen tests (Lambert-Niclot et al., 2020). However, even with the increase in clinical testing worldwide since the start of the SARS-CoV-2 pandemic, challenges persist in evaluating community health through diagnostic testing (Tromberg et al., 2020). It was evident in the literature that individual diagnostic testing is often used to screen staff and students; however, we also found that it can be hampered by logistical difficulties, high cost, and has a lack of long-term sustainability (LaTurner et al., 2021).

1.6 Wastewater-based monitoring initiatives that have been utilized to examine the spread of SARS-CoV-2 in universities and other settings.

Wastewater surveillance (WWS), also known as wastewater-based epidemiology (WBE), provides a rapid and cost-effective way to gather comprehensive health data at the local, regional, national, and even global level (Georgia National Wastewater Surveillance System (GA

NWSS), n.d.). Near the onset of the pandemic, the Netherlands was one of the first countries to use WWS to detect SARS-CoV-2 RNA in wastewater samples (Medema et al., 2020). Through an expansive literature search, we found reports of various levels of institutions using WWS as a tool to determine early warning signs of surges in SARS-CoV-2 cases in surrounding communities. One study done on the Emory University campuses found that SARS-CoV-2 RNA could be detected in wastewater samples approximately two weeks before the occurrence of a surge in cases (Liu et al., 2022). This implies that wastewater monitoring could serve as an early warning system for potential outbreaks before diagnostic tests. Another study conducted in Houston, Texas, monitored SARS-CoV-2 in wastewater across 51 public schools and determined that school wastewater surveillance was reflective of local infections at several population levels and played a crucial role in the detection and mitigation of outbreaks (Wolken et al., 2023). A study done in San Diego, California found that passive environmental surveillance could detect the presence of SARS-CoV-2 cases in non-residential community school settings with a high degree of accuracy (Fielding-Miller et al., 2023). Wastewater-based monitoring (WBM) is a promising alternative method for detecting and controlling the spread of SARS-CoV-2 in schools. WBM involves the collection and analysis of sewage samples for the presence of SARS-CoV-2 RNA, providing a means of detecting and tracking the spread of the virus in a community (Castro-Gutierrez et al., 2022). WBM has several benefits over traditional diagnostic testing, including its non-invasive nature and ease of implementation, ability to provide real-time information about the presence of SARS-CoV-2 in a school community for prompt preventive measures, and potential to detect asymptomatic or pre-symptomatic cases (Liu et al., 2022).

1.7 Lack of studies that have examined the relationship between costs associated with conducting wastewater epidemiology in public schools compared to diagnostic testing.

To date, only two studies have evaluated the financial expenses and the cost-effectiveness of WBM as a strategy to monitor the spread of SARS-CoV-2; (Hart & Halden, 2020), (LaTurner et al., 2021). While WBE has shown promise as a tool for SARS-CoV-2 monitoring, there has been limited research on the costs and feasibility of implementing this method in schools. The need for information about the cost of weekly wastewater sampling and analyses for SARS-CoV-2 in public schools is recognized as an important aspect of SARS-CoV-2 pandemic response (LaTurner et al., 2021). As schools face the challenges of the ongoing COVID-19 pandemic, it is critical to understand the costs associated with various approaches to measuring and mitigating disease spread. Decision-makers can evaluate the advantages and disadvantages of different surveillance measures and draw conclusions regarding how to allocate resources by gathering data on the costs of weekly wastewater sampling and analysis (Budgeting for Environmental Health Services in Healthcare Facilities: A Ten-Step Model for Planning and Costing - PMC, n.d.). By collecting data on the costs of weekly wastewater sampling and analysis, it is possible to understand the financial implications of various strategies and identify potential cost-saving opportunities (Budgeting for Environmental Health Services in Healthcare Facilities: A Ten-Step Model for Planning and Costing - PMC, n.d.). However, there are various challenges to analyzing the cost of weekly wastewater sampling (Safford et al., 2022). Two challenges are the lack of standardization and duplicate information available on cost measures and process of reporting of these costs (Safford et al., 2022). The gap in standardization of costs associated with wastewater monitoring is evident, therefore it is essential to conduct further research to develop a standardized way of evaluating these costs.

1.8 Summarize the current problem of SARS-CoV-2 spread in public schools and the significance of the study in understanding the costs associated with monitoring and preventing transmission in these communities.

As the SARS-CoV-2 pandemic continues and concerns from K-12 communities rise regarding the transmission of SARS-CoV-2 in schools; the literature gaps on costs and feasibility require further research. Especially, there is a need for more research on the costs and feasibility of implementing WBE versus diagnostic testing to monitor the burden and spread of SARS-CoV-2 in public schools. Further research regarding costs of monitoring measures is needed to provide information about the resources needed to ensure safety of school administration, staff, teachers, and students. A deeper understanding of costs associated with these two monitoring approaches will aid stakeholders to make key decisions regarding which monitoring approach to implement and how to effectively allocate resources to monitor and mitigate the spread of SARS-CoV-2. Timely and accurate surveillance information enables school leadership and health authorities to better plan for maintaining a safer learning environment. Additionally, school-based disease surveillance can aid in policy development that help mitigate the impact and of the SARS-CoV-2 in K-12 communities.

Chapter 2. Introduction, Research Objectives, and Rationale

Given the emergence of new variants and unequal access to vaccines worldwide, it is uncertain when the SARS-CoV-2 pandemic will come to an end and what its lasting impact will be. This uncertainty only amplifies the communities' concerns for children and their future. Since the beginning of the pandemic, it is estimated that more than 13.9 million children under 18 years of age have been infected with SARS-CoV-2 (Michaud & Dietz, 2023). SARS-CoV-2 has resulted in a devastating loss of human life and presents an unparalleled challenge for public health as it is ranked among the top ten causes of death for children 5-11 years of age as of July 2022

(*COVID-19 Is a Leading Cause of Death in Children and Young People in the US | University of Oxford*, 2023). School-aged children are not only susceptible to SARS-CoV-2 but can play a role in transmitting the virus through educational settings.

To address the challenges posed by the SARS-CoV-2 pandemic in schools, various interventions have been implemented, including diagnostic testing, mask mandates, upgrading air systems, increased cleaning and disinfection, remote learning, and quarantine measures (*COVID-19 Guidance for Safe Schools and Promotion of In-Person Learning*, n.d.) and (*K-12 State Reopening Plans · The Hunt Institute*, n.d.). However, these approaches can be costly and may not provide real-time information about the spread of SARS-CoV-2 within a school community. A monitoring measure that has gained attention recently is wastewater-based epidemiology (WBE), which involves the sampling and analysis to detect the presence of SARS-CoV-2 in fecal waste. WBE has been utilized at colleges and universities to monitor the prevalence and spread of SARS-CoV-2 across the campuses (Harris-Lovett et al., 2021), but few studies have examined the application and effectives of this approach in K-12 public schools or examined the school-related factors and community factors that can influence the transmission and detection of SARS-CoV-2 in school settings.

This study examines the activity-based cost (ABC) of using WBE in Atlanta Public Schools as a tool for monitoring SARS-CoV-2 infections, and other infectious diseases, in school settings and compares this to the cost of diagnostic testing of students and staff.

The main goals of this study are to:

1. Collect and analyze data on the costs of weekly wastewater sampling and analyses for SARS-CoV-2 in selected Atlanta Public Schools.
2. Collect data on the costs of COVID diagnostic testing in Atlanta Public Schools during the academic year (August 2021-May 2022 and August 2022 – February 2023).
3. Compare the cost of diagnostic testing to wastewater monitoring in Atlanta Public Schools.

Through this research, we aim to provide valuable insights and recommendations for Atlanta Public Schools about the costs associated with SARS-CoV-2 surveillance to inform their decisions and help them plan for the resources needed to sustain school-based SARS-CoV-2 surveillance in the future.

Chapter 3. Methods

3.1 Study Design and Sample Selection

This study is a retrospective cost analysis of wastewater monitoring for SARS-CoV-2 in Atlanta Public Schools compared to diagnostic testing. Data was collected for the academic years of August 2021 to May 2022 and August 2022 to February 2023. A convenience sample of ten Atlanta Public Schools was selected via a feasibility analysis shown in Figure 3. The selection of study schools was a two-part process. The first part of the feasibility analysis involved the Moe Research data team determining proximity of manholes to locate eligible schools via sewer pipe shapefiles in QGIS, identifying manholes that served only schools, accessibility of manholes via satellite viewing, and curating a list of schools that were eligible. The second part of the feasibility analysis involved the Moe Research sampling team who visited and evaluated each of the eligible manholes and confirmed with APS health officials that eligible manholes were solely serving schools.

Wastewater monitoring sample sites and samples were collected in partnership with the City of Atlanta's Department of Watershed Management (DWM) and Atlanta Public Schools, all schools in the community are shown in Figure 4a and 4b. School sample sites listed in Table 1 were initially chosen due to their proximity in underserved communities in South Atlanta where the Moe Research Team had already been collecting wastewater samples from community manholes. Additionally, these ten schools were chosen based on the availability and accessibility of sewer manholes that exclusively served the school buildings.

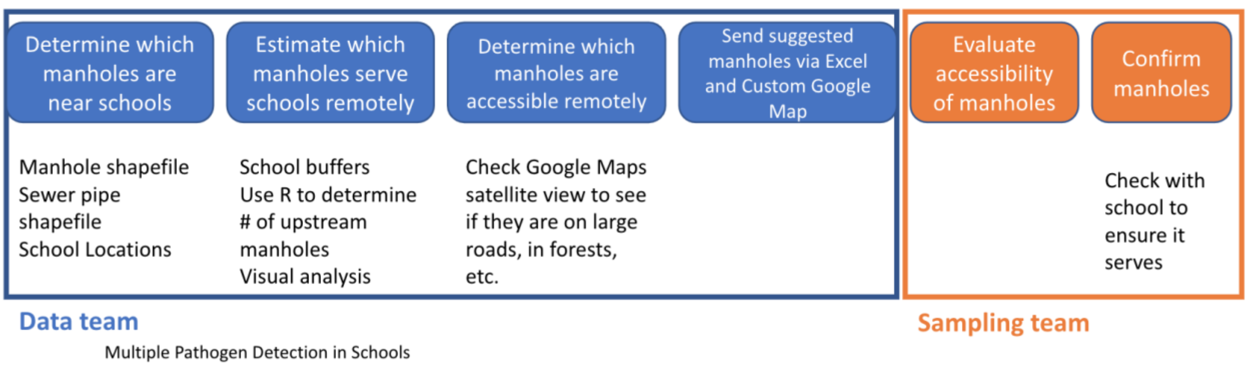

Figure 3 developed by Moe Research team member Stephen Hilton. This figure describes the process of selecting study schools with accessible manholes for the sample collection.

Initial Study Schools	**Number of Students Enrolled**	**Number of Staff Employed**
Tuskegee Airmen Global Academy	514	78
Dobbs Elementary School	368	62
Herman J. Russel West End Academy	390	59
Perkerson Elementary School	370	60
Finch Elementary	366	74
Agnes Jones Elementary School	465	73
Jean Childs Young Middle School	809	108
Peyton Forest Elementary School	428	66
John Lewis Invictus Academy	950	118
Benjamin E Mays High School	1244	146

Total	**5904**	**844**

Table 1 displays the ten schools selected by the Moe Research Team and the number of students enrolled for the Academic years August 2021 – May 2022 and Academic period of August 2022 – February 2023. Student enrollment numbers were found via individual school websites. Individual school staff employments were acquired from the APS COVID19 vaccination records.

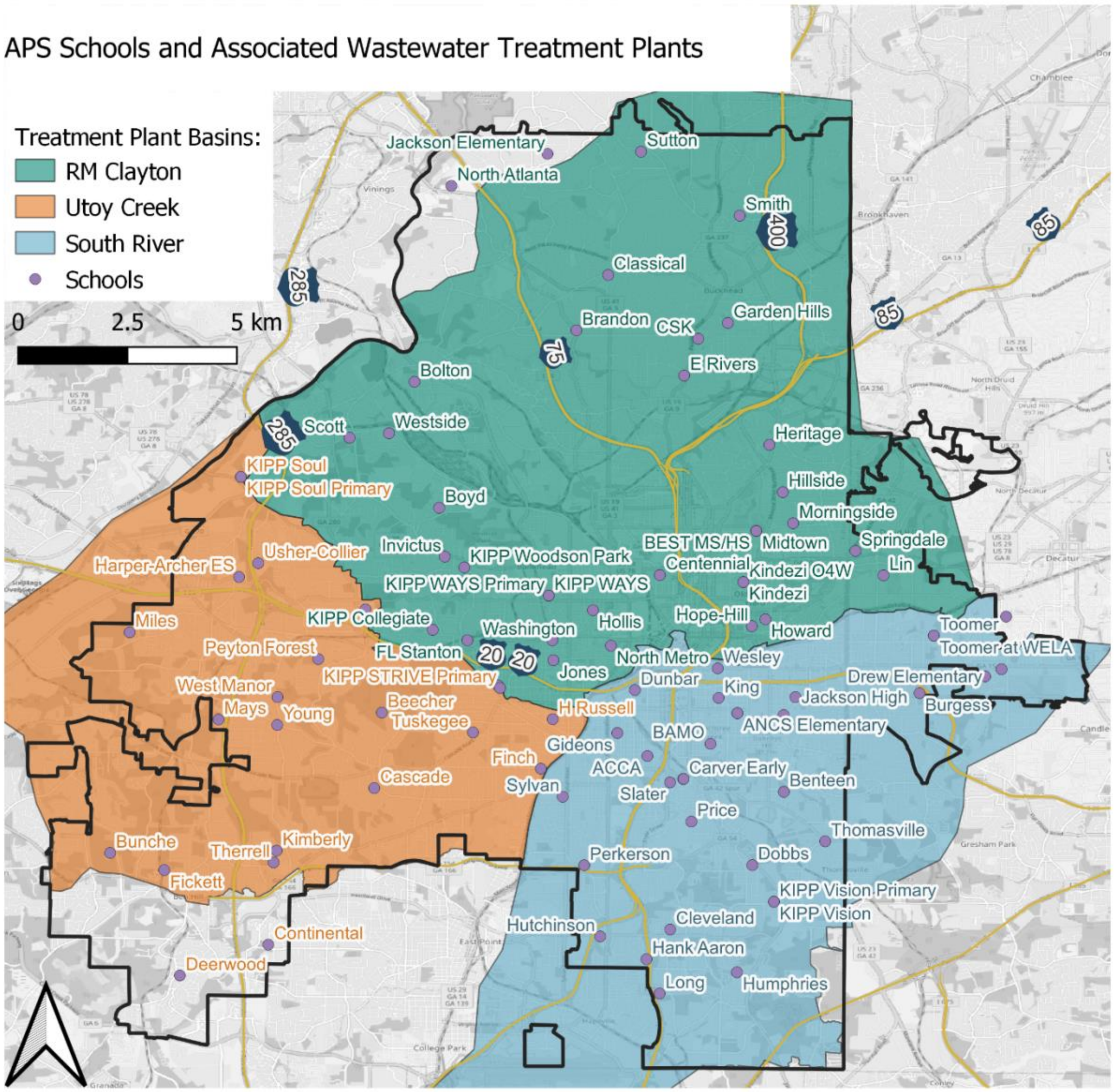

Figure 4a developed by team member Stephen Hilton and Yuke Wang; They used QGIS igraph file of Atlanta's sewer system to analyze wastewater flow between manholes in RStudio. Shapefile polygons were created for each influent line by forming a concave hull around the relevant *manholes, manually edited for overlap and unfilled areas, and a buffer was created to identify APS schools and which wastewater treatment plants and influent lines receive their wastewater.*

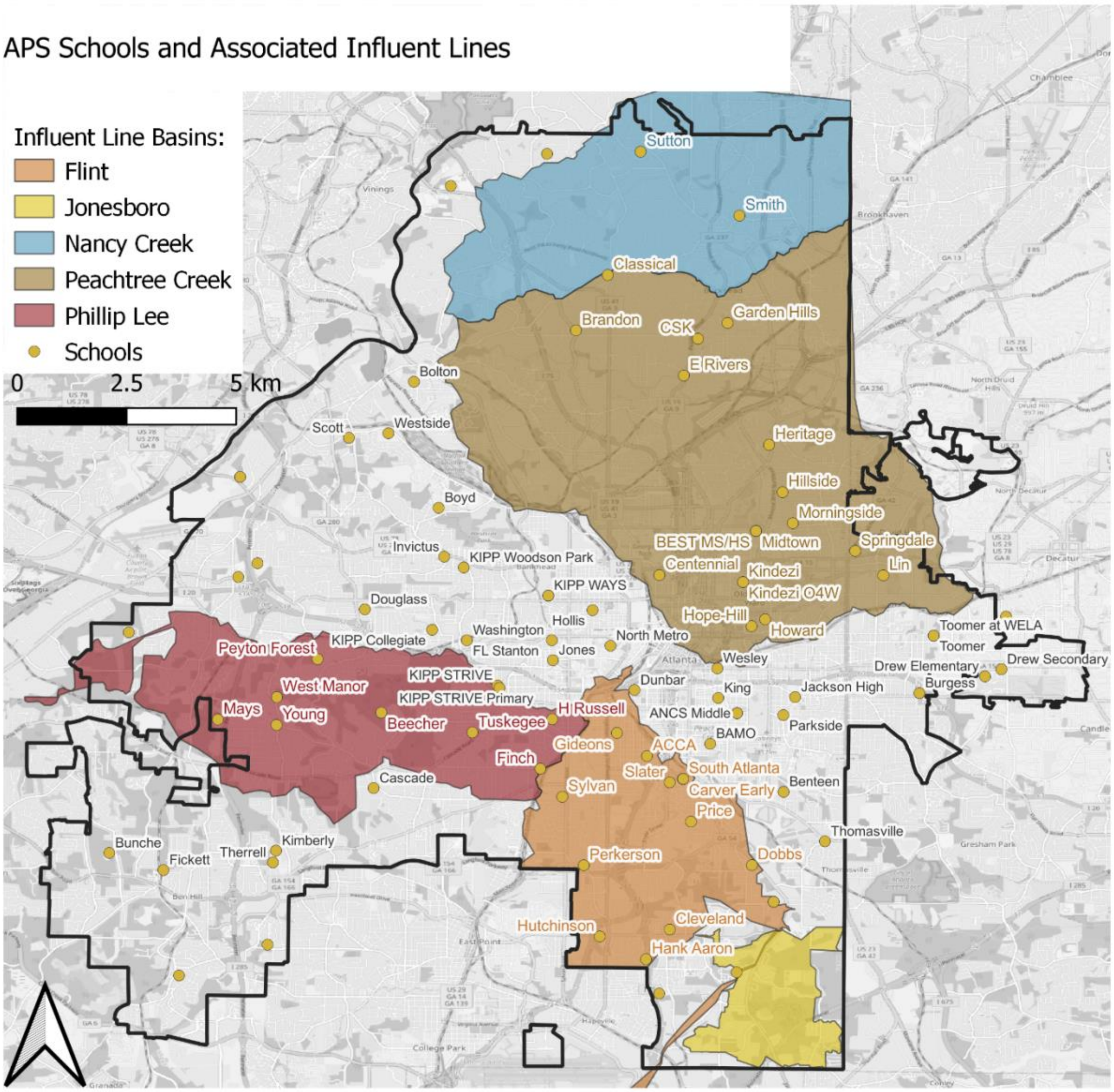

Figure 4b developed by team member Stephen Hilton and Yuke Wang; They created catchments areas for each treatment plant by creating a concave hull around all manholes upstream of the plant. Then they used the catchment areas to determine which treatment plants served each school. The figure presents influent lines that serve each APS school.

3.2 Data Collection

The data collection for this study involved several different methods to gather a comprehensive understanding of the costs of wastewater monitoring and diagnostic testing in Atlanta Public Schools.

3.2.1 Wastewater Monitoring Costs

Weekly Moore swabs as shown in Figure 5 were submerged into the wastewater stream that flow under each of the 10 selected study school manholes, left over 24 hours, and then retrieved the following day. Sampling started in August 2021 at the beginning of each week. Sample collection, as shown in Figure 6 involved swab samples being picked up 24 hours after installation and being transported on ice to the laboratory for processing which took approximately five hours. Detailed information on the costs of weekly wastewater sampling and analysis for SARS-CoV-2 at the ten selected schools was provided by from the Moe research team. The cost breakdown of wastewater monitoring is shown in Table 2 and Table 3 which includes the total cost of supplies and equipment per sample, sample collection and transportation, laboratory analysis cost, and data management and reporting.

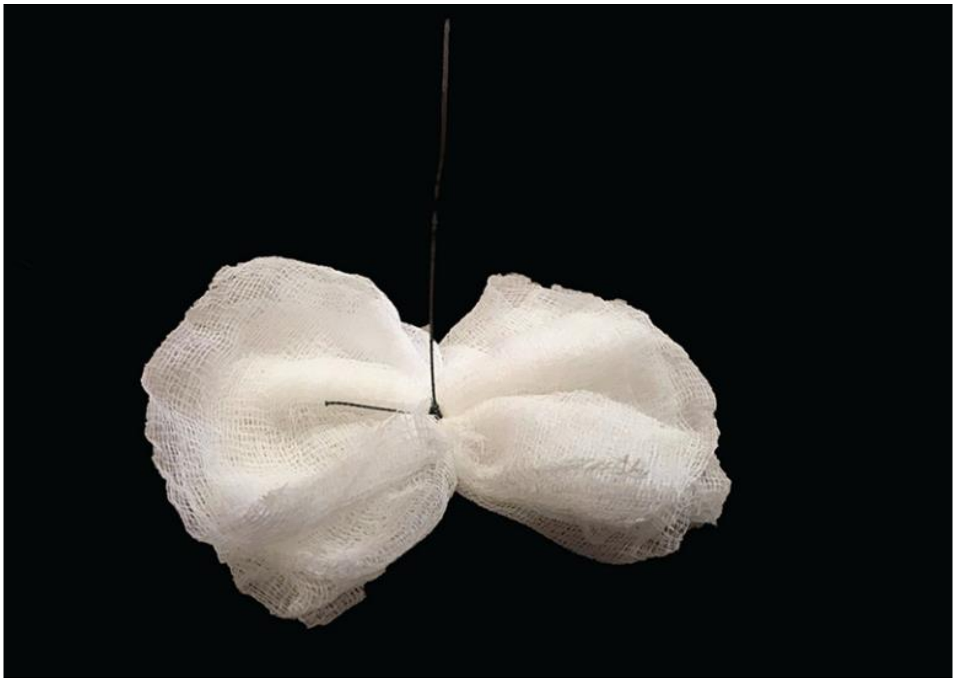

Figure 5 displays the Moore Swab used by the Moe Research Team for wastewater surveillance sampling. Figure provided by Moe Research Team.

Figure 6 Collection process of wastewater monitoring samples and processing of sample. Figures on the far left and middle were taken by Moe Research team member Shazneen Damani, and figure on far right was provided by the Moe Research team.

Type of Product	Item Name	Unit of Product	Unit Price ($)
Consumable	50 ml Corning Centrifuge Tube (Rnase/Dnase free)	500	302
Consumable	Moore Swab	10	12
Consumable	15 ml Corning Centrifuge Tube	500	69
Consumable	waste bag rack	6	119
Consumable	small waste bag	800	239
Consumable	KIMWIPES™ large 37x42cm	15/case	86
Consumable	Dishwashing Detergent, 0.8 Liter	1	6
Consumable	Bleach	1 bottle	45
Consumable	Timer	1	51
Consumable	Autoclave tape	1	6
Consumable	Large trash bag	200	250
Consumable	Aluminum foil	1	14
Consumable	Hand soap	1	20
Consumable	2ml tubes	5000	323
Consumable	500ml glass beaker	1	10
Consumable	SealRite 1.5 ml micro centrifuge tube (DNAse/RNAse free)	500	16
Consumable	Serological Pipettes, 10mL	400	88
Consumable	Serological Pipettes, 25mL	300	110
Consumable	10 ul Sharp Precision Barrier	960	106
Consumable	1000 ul Sharp Precision Barrier Tips	576	62
Consumable	20 ul Sharp Precision Barrier	960	106
Consumable	200 ul Sharp Precision Barrier Tips	960	106

Consumable	Gloves	1000	94
Consumable	Lab Coat disposible	90	324
Consumable	Disposable n95 respirators	20	20
Consumable	1000p pipet tips (RNAse/DNase-free)	1	103.25
Consumable	200p pipet tips (RNAse/DNase-free)	1	95.10
Consumable	Regular PCR plate for prep	50	200.00
Consumable	Rainin 200uL BioClean Ultra pipette tips	960	81.37
Consumable	Rainin 20uL BioClean Ultra pipette tips	960	81.37
Consumable	Rainin 100uL BioClean Ultra pipette tips	960	81.37
Consumable	Rainin 1000uL BioClean Ultra pipette tips	768	81.37
Consumable	1 set pipettes (1000ul, 100ul, 10ul)	1	1,000
Consumable	Ethanol	1	300
Consumable	Electronic Pepitor 1-20 UL	-	636
Consumable	Electronic Pepitor 10-200 UL	-	636
Consumable	Electronic Pepitor 50-1000UL	-	636
Reagent	Thermo Scientific Magmax extraction kit	1000	4000
Reagent	TaqPath singlex PCR kit	5000	2300
Reagent	SARS-CoV-2 standard	-	541

Reagent	Bovine Respiratory Syncytial Virus	1	20
Reagent	Molecular Water (Rnase/Dnase free)	1	52
Reagent	SARS-CoV-2 Primers/probe set	1	850
Reagent	BRSV primers/probe set	1	140
Reagent	Nanotrap particles & binding buffer	1	6

Table 2 information provided by team member Sarah Durry. This table provides a list of various items required for wastewater surveillance sample collection and processing along with their associated unit prices. The table includes 50 different items, which are classified as either reagents or consumables. The first column of the table indicates the type of product, which specifies whether the item is a reagent or consumable. The second column lists the item name, and the third column specifies the unit of the product, such as quantity or volume and the fourth column indicates the unit price of the item.

Items	***Calculation***	***Total ($)***
Moore swab supplies for 10 schools	$1.20 per swab * 10 samples	12
Sampling Team Labor cost	$18/hour * 8 hours	144
Transportation cost gas	30 gal * $3.33 per gal	100
Car rental	$75	75
** PCR Test Supplies	$90 * 10 samples	900
Lab team labor cost	($32/ hour * 5 hours) + ($27/ hour * 5 hours)	295
Data analysis and report generation cost	$33/hour * 5 hours	165
Total	-	1691

Table 3 presents the weekly cost for wastewater monitoring for ten schools. The double asterisks (**) represents the weekly lab supply costs for analyzing the samples. Estimates for test supplies were provided by Moe Research Team member: Dr. Marlene Wolfe. Car rental estimate was provided by team member Lauren Briggman.

3.2.2 Diagnostic Testing Costs

Data on the costs of COVID diagnostic testing in schools were collected from the Georgia Department of Public Health, data available via the internet, and the selected Atlanta Public Schools (APS). This cost breakdown includes the cost of purchasing and administering tests via outside contractors, as well as any school staff or other resources required for testing. APS implemented required diagnostic testing for all staff members and optional testing for students. The diagnostic testing process encompassed the following: swabbing of both nasal cavities for five second by Virial Solution contractors (https://viralsolutions.com/), then swabs were placed in testing cards along with the reagent, and the test results took 20 minutes. Students who tested positive were isolated and placed in a CARE room until picked up by their guardians. The frequency of testing occurred twice per week with a three-day span between the first and last test. The reasoning behind the frequency of testing was to enable APS to better understand the disease prevalence and transmissibility within the school community to protect students and staff and maintain a healthy environment.

3.2.3 Classification of surveillance costs

The costs of both surveillance approaches were classified into direct and indirect costs and further organized as variable or fixed costs Tables 4a and 4b. Direct costs include the cost of diagnostic tests and wastewater testing supplies which can be estimated on a per test basis, while indirect costs encompass transportation and personnel hours/labor costs, and other expenses related to collection, processing and analyses of wastewater samples or dissemination and administration of diagnostic tests. Fixed costs refer to costs that are incurred regardless of the level of testing, such as maintenance of equipment, and salaries. Variable costs, on the other hand, are directly related to the volume of testing, including the number of personnel involved, the frequency of testing, and the average number of tests conducted weekly. By developing a detailed breakdown of the different cost items, the table can help us better understand the costs associated with surveillance activities, and make more informed decisions regarding resource allocation, budgeting, and cost optimization.

Category	**Cost Item**
Direct Cost	
	Cost of wastewater testing supplies
Indirect Cost	
	Equipment cost for wastewater testing
	Number of personnel involved in wastewater sample collection and analysis
	Frequency of testing
	Average number of wastewater tests conducted weekly for staff and students
	Personnel hours spent on wastewater sample collection and analysis
Fixed Cost	
	Salaries
Variable Cost	
	Cost of wastewater testing supplies
	Number of personnel involved in sample collection and analysis
	Frequency of testing
	Average number of wastewater tests conducted weekly for staff and students
	Personnel hours spent on wastewater sample collection and analysis

Table 4a provides a breakdown of various costs associated with wastewater testing activities. The costs are categorized into four types: direct, indirect, fixed, and variable costs.

Category	**Cost Item**
Direct Cost	
	Cost of diagnostic testing supplies
Indirect Cost	
	Equipment cost for diagnostic testing
	Number of personnel involved in diagnostic testing
	Average number of diagnostic tests conducted weekly

	Average number of diagnostic tests conducted weekly
	Personnel hours spent on diagnostic testing
Fixed Cost	
	Salaries
Variable Cost	
	Cost of diagnostic testing supplies
	Number of personnel involved in diagnostic testing
	Average number of diagnostic tests conducted weekly
	Personnel hours spent on diagnostic testing

Table 4b provides a breakdown of various costs associated with diagnostic testing activities. The costs are categorized into four types: direct, indirect, fixed, and variable costs.

3.3 Data Analysis:

The collected data were analyzed using both quantitative and qualitative methods to provide a comprehensive understanding of the costs of wastewater monitoring and diagnostic testing in Atlanta Public Schools. The collected data were analyzed using statistical software, RStudio (*RStudio Desktop - Posit*, n.d.), to compare the costs of diagnostic testing to wastewater monitoring in Atlanta Public Schools. An Activity-Based Cost (ABC) analysis Model was developed to identify the major cost drivers for each surveillance approach. This process involved identifying the activities associated with wastewater monitoring and diagnostic testing and allocating the associated costs to those activities. A sensitivity analysis was conducted to generate a range of costs that could occur due to changes in testing levels and inflation. The data was also used to identify trends and patterns in the costs and impacts of the two approaches.

3.4 Mathematical ABC and sensitivity Analysis Model and Model Structure

This study utilized the R programming language (*R: The R Project for Statistical Computing*, n.d.) to build an Activity-Based Cost Analysis Model and Sensitivity Analysis Model. These models were used to compare the costs of diagnostic testing and wastewater testing for ten selected Atlanta Public Schools. The model was run over two time periods coinciding with APS academic calendar for the 2021-2022 and Fall 2022 to Mid Spring 2023.

3.4.1 Activity Based Cost Analysis Model and Model Structure

We conducted three Activity-Based Cost Analysis Models to compare the cost of implementing diagnostic testing and wastewater testing in 10 selected schools in the APS clusters for the academic year 2021-2022 and Fall 2022 to February 2023. The parameters and sources are listed in Tables 5 and 6.

The diagnostic testing cost inputs included:

- Contractor (Viral Solutions) cost per Rapid Antigen test of $20
- A testing frequency of twice a week according to the testing schedule provided by APS (*COVID-19 Surveillance Testing Schedule (Effective 08/01/2022)* 2022).
- 50% of the student population being tested during the 2021- 2022 academic year. This percentage was sourced from the contractors press release for APS surveillance testing (*Atlanta Public Schools Aims to Test Thousands Weekly for COVID-19*, n.d.).
- 35% of the student population being tested during the Fall 2022 to February 2023 time period. This percentage was sourced from an article interviewing the contractor for the 2022-2023 academic year (Sonnad-Joshi, n.d.).
- 844 staff members being tested weekly for both time periods. This number was sourced from the APS COVID-19 Vaccination records (*Updates + Alerts / Self-Report+ Weekly Case Report*, n.d.).

Parameters	**Value**	**Calculations**	**Assumptions**	**Reference**

Cost per Rapid Antigen test	$20	None	The cost includes labor and time from the contractor	(Durry, *Viral Solutions cost estimate per test* 2023)
Weekly Testing frequency students	2	None	Students are being tested twice a week	(*COVID-19 Surveillance Testing Schedule (Effective 08/01/2022)* 2022)
Weekly Testing frequency staff	2	None	None	(Public Schools, 2021)
Total Number of Students participating in diagnostic testing for the academic year 2021-2022	2952	5904 total students enrolled *0.5	50% of all students enrolled are getting tested twice weekly	(*Atlanta Public Schools Aims to Test Thousands Weekly for COVID-19*, n.d.)
Total Number of Students participating in diagnostic testing for Fall 2022 – February 2023	2066	5904 total students enrolled *0.35	35% of all students enrolled are getting tested twice weekly	(Sonnad-Joshi, n.d.)

Total Number of Staff participating in diagnostic testing for academic year 2021-2022	844	Refer to Table 1	All staff members are getting tested twice weekly	
Total Number of Staff participating in diagnostic testing for academic year Fall 2022 – February 2023	844	Refer to Table 1	All staff members are getting tested twice weekly	(*Updates + Alerts / Self-Report+ Weekly Case Report*, n.d.)
Total Number of Weeks of School for the Academic year 2021-2022	37	None	None	
Total Number of Weeks of School for Fall 2022 – February 2023	25	None	None	

Table 6 presents individual parameters and sources from the literature that were input into the ABC model for diagnostic testing for the Academic year 2021- 2022 and Fall 2022 – February 2023.

The wastewater testing cost inputs included:

- A weekly cost of $1,691 for ten study schools
- A testing frequency of once a week
- 1 sample per week collected from a total of ten schools.

Parameters	**Value**	**Calculations**	**Includes**	**Assumptions**
Total Cost per wastewater sample for 10 schools	$1,691	Refer to Table 3 and Table 4	• Cost of Moore swab supplies for 10 schools • Sampling team labor cost • Transportation cost • Lab equipment cost • Lab team labor cost • Data analysis and report generation cost	None
Weekly Testing frequency	1	None	None	Each school tested same amount of time
Total Number of Weeks of School for the Academic year 2021-2022	37	None	None	None

Total Number of Weeks of School for Fall 2022 – February 2023	25	None	None	None
Number of schools	10	None	None	None
Total Number of Wastewater samples collected for the academic year 2021-2022	370	37 weeks * 10 schools	None	None
Total Number of Wastewater samples collected for Fall 2022 – February 2023	250	25 weeks * 10 schools	None	None

Table 7 presents individual variable values that were inputted into the ABC model for wastewater testing for the Academic year 2021- 2022 and Fall 2022 – February 2023. All parameters were sourced from the Moe Research Team

In order to calculate the diagnostic testing cost for students we first determined the total number of students attending each of the 10 schools then proceeded to multiply by 50% and 35% for the corresponding academic year. This calculation in shown in Table 6. Then we determined the cost per day and cost per week by multiplying the total cost per test by total the number of tests conducted per day and week, respectively. The cost of wastewater testing was calculated by determining the total cost per school each week (one sample per week). The average cost per student was estimated by dividing the total weekly cost per school by the total number of students attending the 10 schools. Using the cost data parameters, R and a package within R, ggplot2, were used to analyze and visualize results.

3.4.2.Sensitivity Analysis Model and Model Structure

We conducted a sensitivity analysis to estimate a range of reasonable costs by varying important parameters such as testing frequency and inflation. The data and parameters used for this model are listed in Table 8 and Table 9

Parameters	**Value**	**Calculations**	**Includes**
Total Cost for wastewater sample per 10 schools	$1,691	Please refer to table 3	• Cost of Moore swab supplies for 10 schools • Sampling team labor cost • transportation cost • Lab equipment cost • Lab team labor cost • Data analysis and report generation cost
Weekly Testing frequency	1	None	None
Total Number of tests range for	10, 50, 100	None	None

wastewater samples			
Inflation Rates	0.02, 0.05, 0.1	None	None
Total Number of people	6748	5904+844	Total student population plus total amount of staff present at 10 schools

Table 8 presents individual items that were inputted into the Sensitivity model for wastewater testing. All parameters were sourced from the Moe Research Team

Parameters	**Value**	**Calculations**	**Includes**
Cost per Diagnostic sample	$20	None	N/A
Weekly Testing frequency	2	None	N/A
Total Number of tests per day	2952	None	50% of total student population from 10 selected schools
Number of tests range	1000,2000,5000	None	None
Inflation Rates	0.02, 0.05, 0.1	None	None
Total Number of people	6748	5904+844	Total student population plus total amount of staff present at 10 schools

Table 9 presents individual items that were inputted into the Sensitivity model for diagnostic testing.

Utilizing the parameters shown in Table 8 and 9, the costs per student week was calculated for 27 different scenarios using 3 different conditions for the number of samples collected, and inflation. The costs for each surveillance method were calculated separately. The total costs for each scenario were adjusted for inflation rates and were stored for each of the 27 scenarios considered in the study. The results were analyzed by estimating the maximum and minimum cost per student per week for diagnostic and wastewater surveillance approaches. R and a package in R, ggplot2, was used to estimate descriptive statistics and visualize results.

Chapter 4 Results

4.1 ABC Model results

The study's first simulated ABC analysis model for the academic year 2021 – 2022 examined at the cost per student and results are shown in Figures 7, 8, and 9. The total number of diagnostic tests estimated per week for students was 5904 for the ten selected schools. This number was estimated by adding the total number of students across the ten selected schools and multiplying by 50% and then multiplying by 2 to account for the frequency of testing. The first model's results revealed that the total cost per week for diagnostic surveillance at all ten schools was $118,080. This is based on the cost of the tests themselves and contractor time. The total cost per week for wastewater surveillance at all ten schools was $1,691, which includes the cost of collecting and analyzing samples, as well as personnel costs. On a per-school basis, the average cost for diagnostic surveillance and individual school cost are shown in Figure 10, 11 and Table 11. This includes the cost of the tests and contractor time to conduct the rapid antigen testing at each individual school. Our results found that the minimum total cost per school for diagnostic surveillance was $7,320, while the maximum total cost per school was $24,880. For wastewater surveillance, the average weekly cost per school was $169.10 shown in Figure 10. When looking at the per-student cost per week, diagnostic surveillance estimated as $20 per student. This estimate was based on the total cost of diagnostic tests divided by the total number of students enrolled (not the number that tested) at all 10 schools each week. The per-student cost for wastewater surveillance was $0.29.

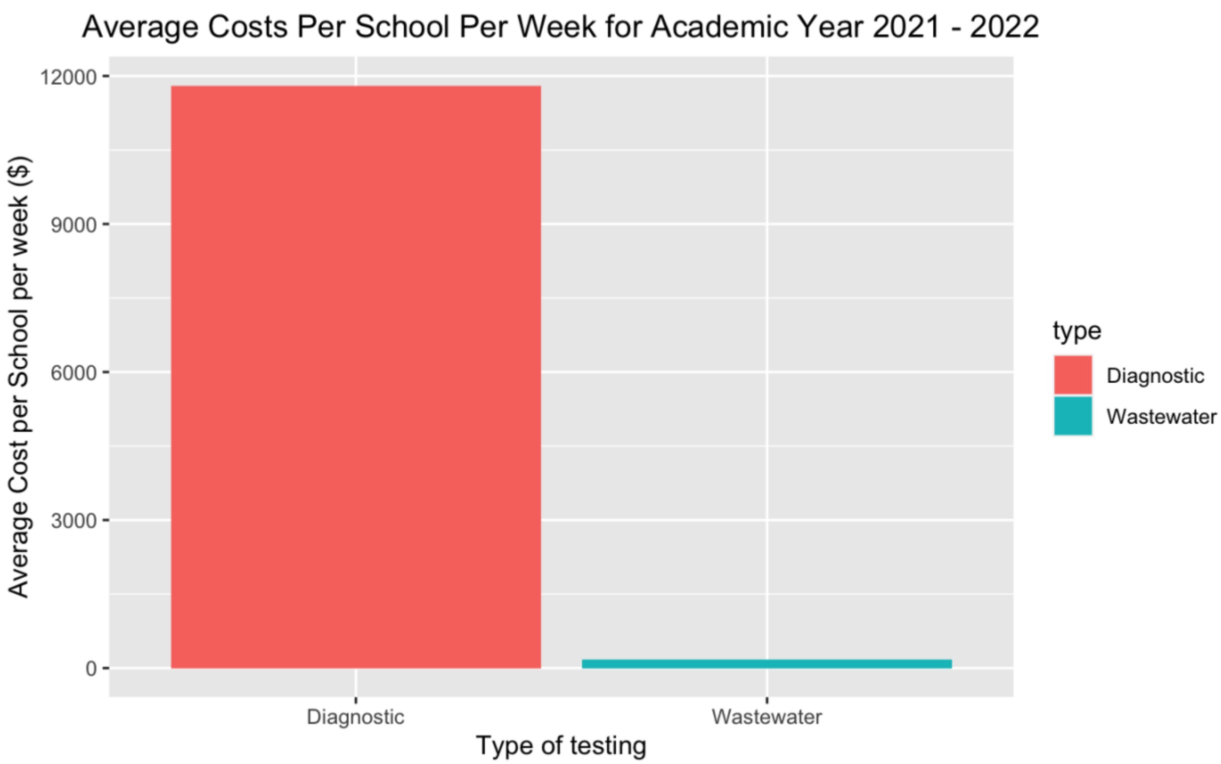

Figure 7 is a bar plot showing the average costs per school per week for diagnostic ($11,808) and wastewater ($169.10) surveillance for the academic year 2021-2022.This estimate only includes the cost of diagnostic testing for students. The x-axis shows the type of surveillance approach, while the y-axis shows the average cost per school per week in US dollars.

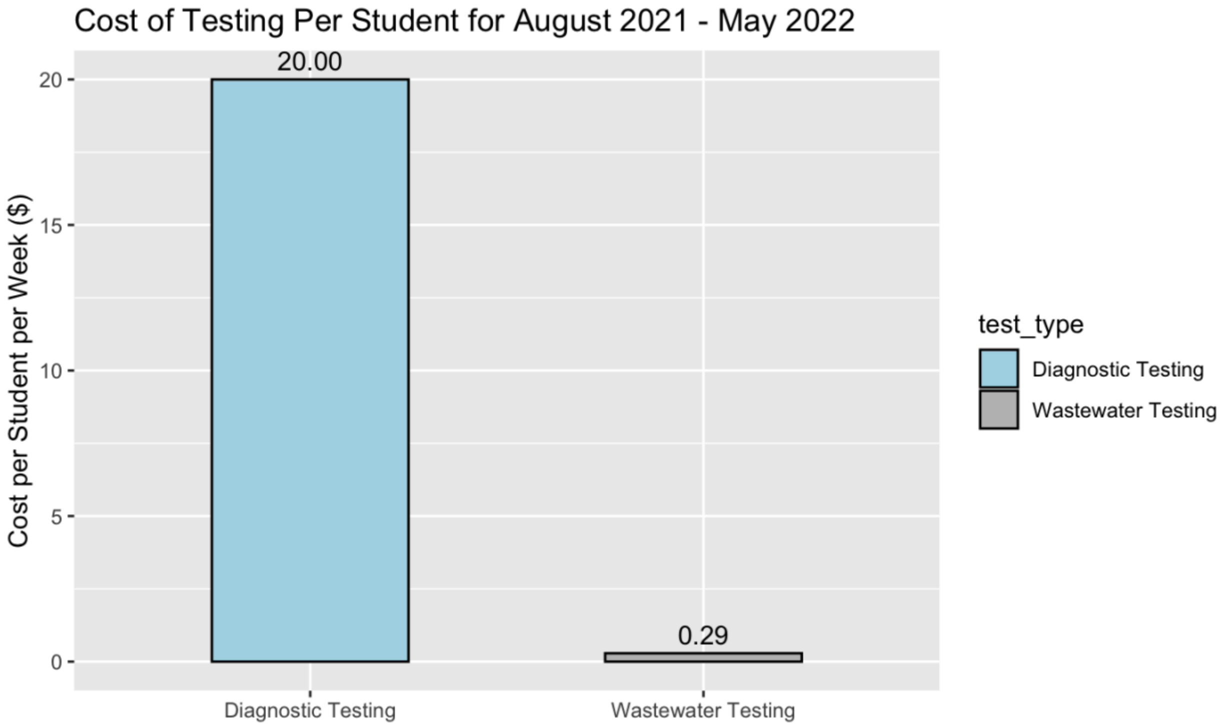

Figure 8 is a bar graph that displays the cost per student per week for diagnostic surveillance and wastewater monitoring during the academic year 2021-2022. The x-axis of the graph shows the two types of surveillance measures: Diagnostic surveillance and Wastewater monitoring. The y-axis shows the cost per student per week in dollars.

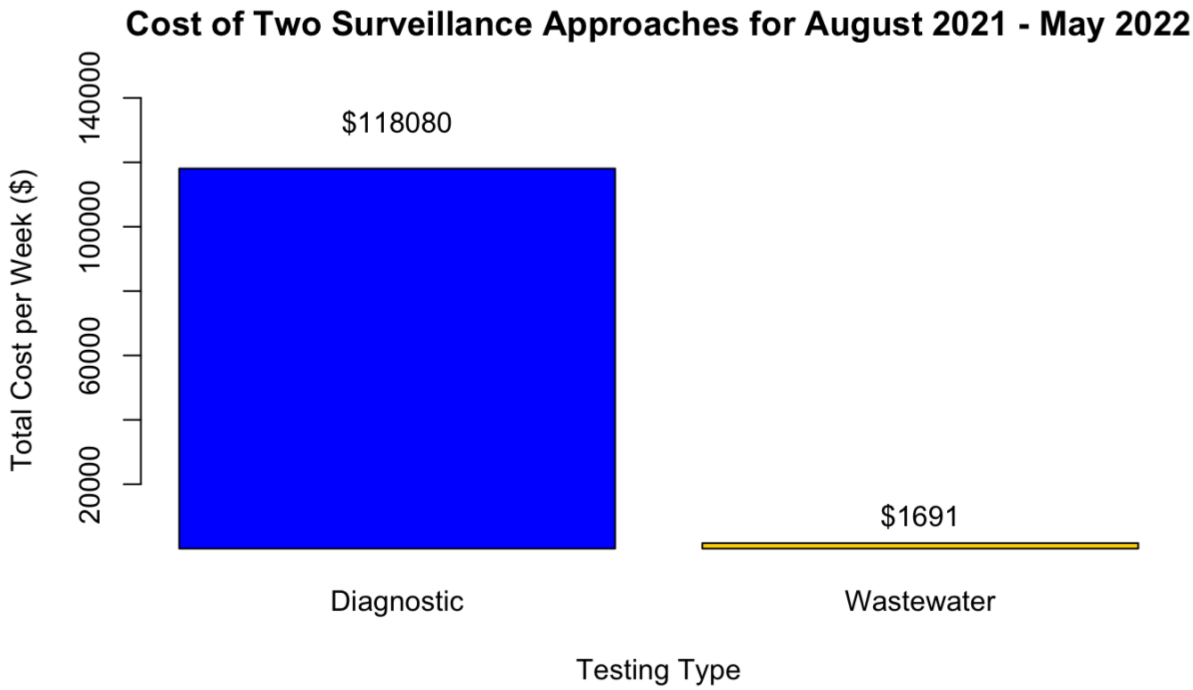

Figure 9 presents the total cost per week for ten schools for two different surveillance approaches. Note that the estimate for diagnostic testing only includes student testing.

Study School	**Total cost for Diagnostic Surveillance Per Week ($)**	**Total Number of Students Enrolled**	**Cost of Diagnostic Surveillance Per Student ($)**
Tuskegee Airmen Global Academy	10,280	514	20
Dobbs Elementary School	7,360	368	20
Herman J. Russel West End Academy	7,800	390	20
Perkerson Elementary School	7,400	370	20
Finch Elementary	7,320	366	20
Agnes Jones Elementary School	9,320	465	20
Jean Childs Young Middle School	16,200	809	20
Peyton Forest Elementary School	8,560	428	20
John Lewis Invictus Academy	19,000	950	20

Benjamin E Mays High School	24,880	1244	20

Table 11 is a table with the individual school cost of diagnostic surveillance *per week for the Academic year 2021- 2022, assuming that 50% of the student population are tested twice per week.*

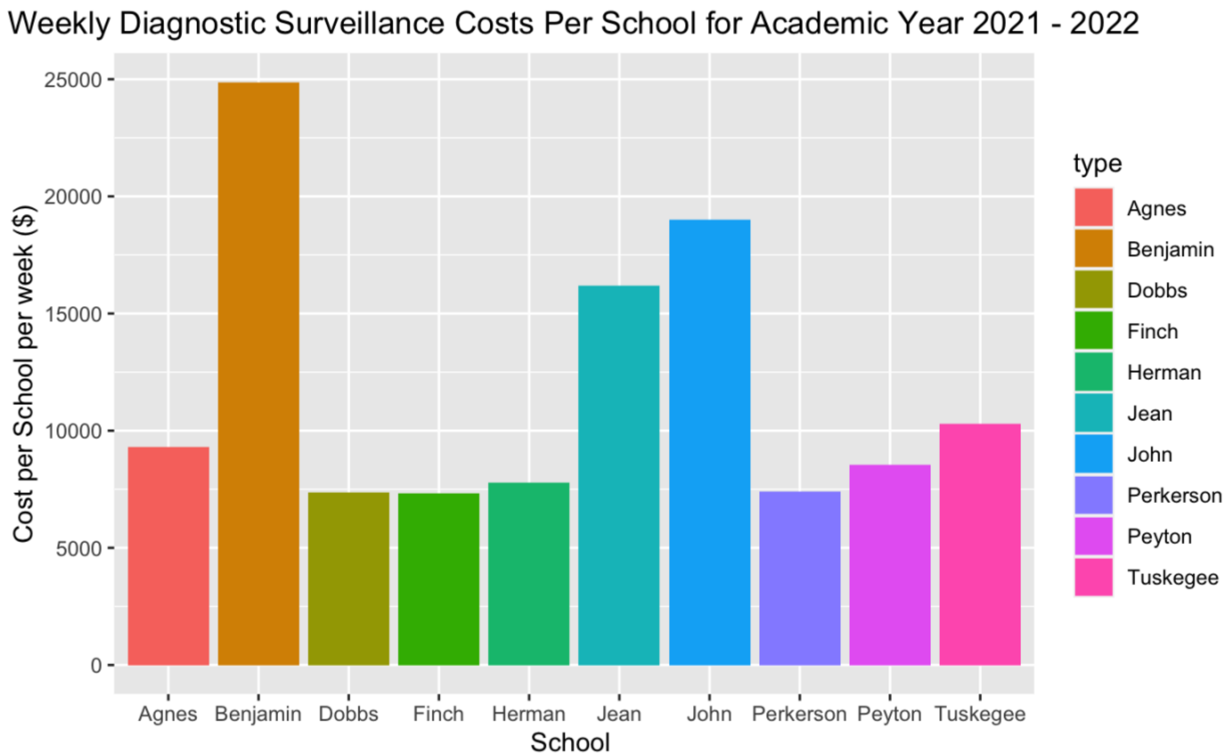

Figure 10 is a bar graph that visualizes the weekly cost per school for diagnostic testing of students. Individual school costs are listed in Table 11.

The second ABC analysis model examined staff diagnostic testing costs for the academic year 2021 – 2022, and results are shown in Figures 11, 12, 13 and Table 12. The total number of diagnostic tests estimated per week for the academic year for staff was 844 for the ten selected schools. This number was estimated by adding up all the staff across each of the ten schools. The staff ABC model's results showed the average cost per week for diagnostic surveillance was $33,760. This estimate included the cost of tests and contractor time to conduct the rapid antigen testing at each individual school. The total average cost per week for wastewater surveillance at all ten schools remained constant at $1,691. This estimate included the cost of collecting and analyzing samples, as well as personnel costs. On a per-school basis, the average cost for diagnostic surveillance and the individual school costs are shown in Figure 14 and Table 12. This includes the cost of the tests and contractor time to conduct the rapid antigen testing at each individual school. On a per-school basis, the average weekly cost for diagnostic surveillance exclusively for school staff was $3,376. This estimate is based on the total cost of diagnostic surveillance divided by the number of staff being tested each week at each school. Wastewater surveillance on a per school basis remained the same at $169.10. The breakdown for per-staff cost per week is the following: diagnostic surveillance comes out to $40 per staff member. This is based on the total cost of diagnostic testing divided by the number of staff being tested each week. The per-school cost, which included total staff and students enrolled for wastewater testing was $2.

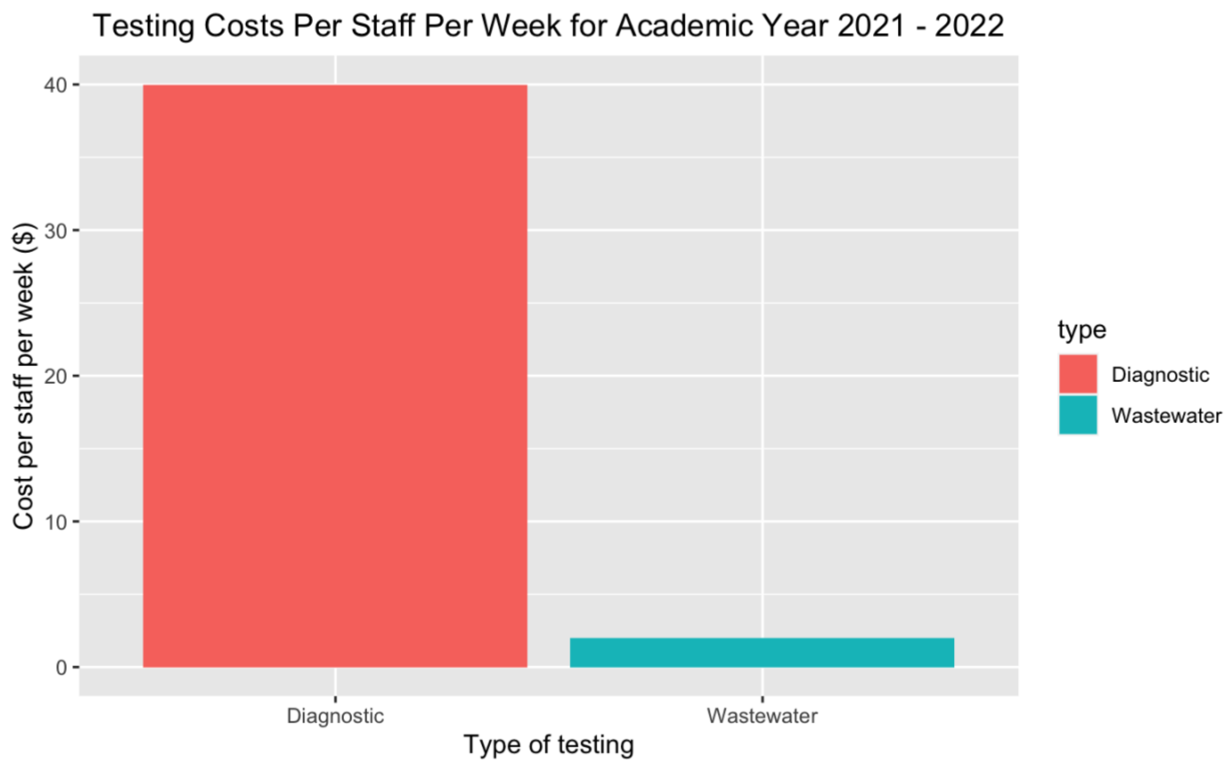

Figure 11 a bar graph that displays the cost per staff per week for diagnostic surveillance and wastewater monitoring during the academic year 2021-2022. The x-axis of the graph shows the two types of surveillance approaches: Diagnostic surveillance and Wastewater monitoring. The y-axis shows the cost per staff per week in dollars.

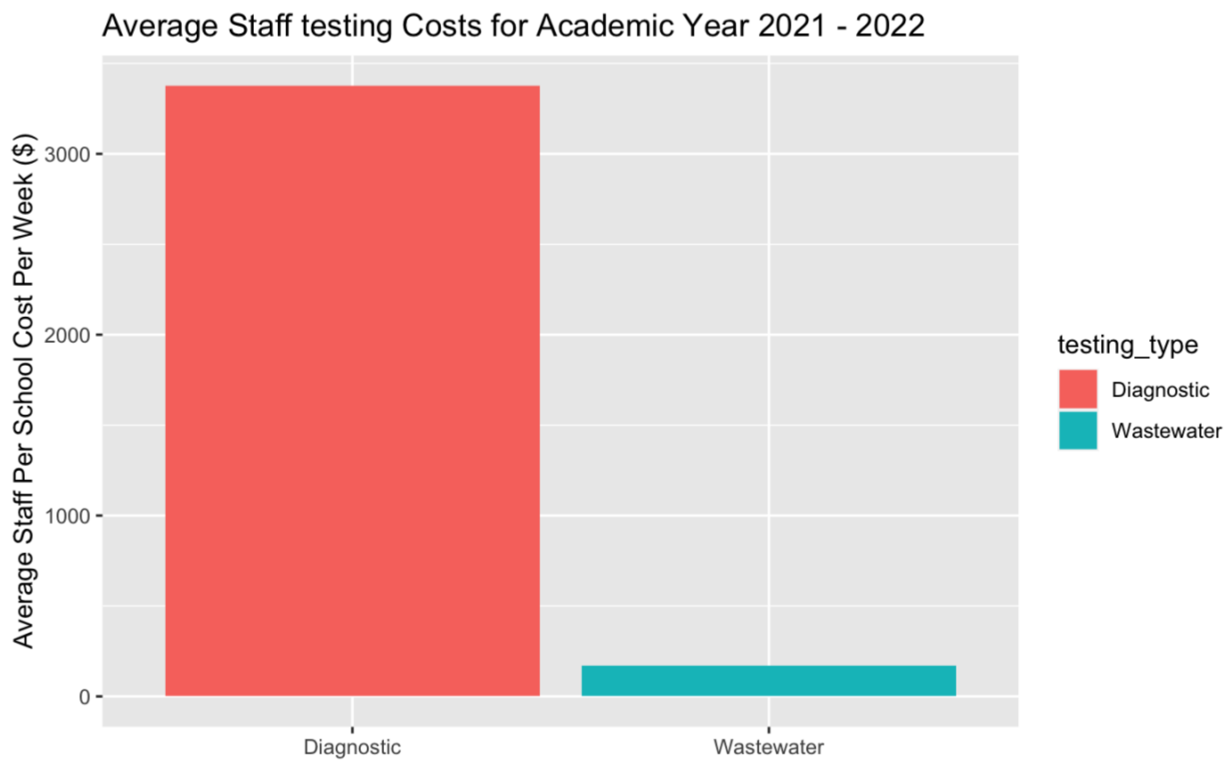

Figure 12 is a bar plot of average weekly staff costs per school for the academic year 2021-2022 for two types of surveillance approaches: Diagnostic surveillance and Wastewater monitoring.

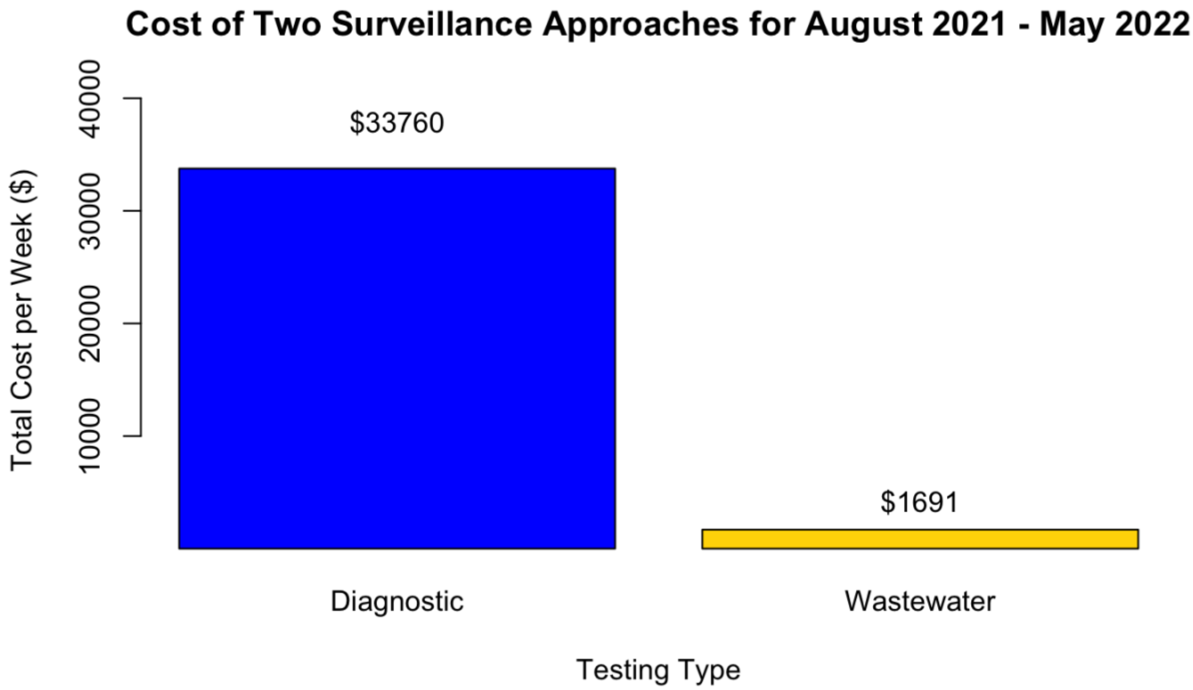

Figure 13 presents the total cost per week of two different surveillance approaches for school staff for all ten study schools.

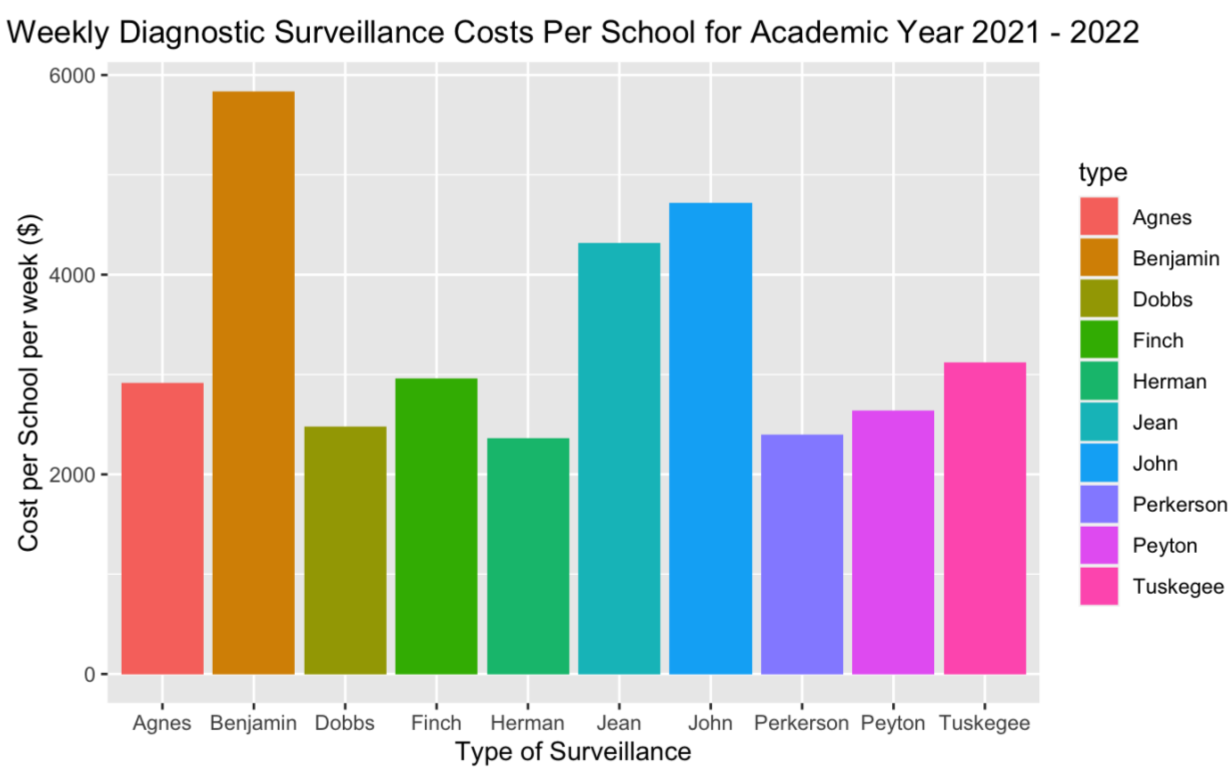

Figure 14 is a bar graph that visualizes the weekly cost per school for diagnostic testing of staff. Individual school costs are listed in Table 12.

Study School	**Total cost for Diagnostic Surveillance Per Week ($)**	**Total Number of Staff Enrolled**	**Cost of Diagnostic Surveillance Per Staff ($)**
Tuskegee Airmen Global Academy	3120	78	40
Dobbs Elementary School	2480	62	40
Herman J. Russel West End Academy	2360	59	40
Perkerson Elementary School	2400	60	40
Finch Elementary	2960	74	40
Agnes Jones Elementary School	2920	73	40
Jean Childs Young Middle School	4320	108	40
Peyton Forest Elementary School	2640	66	40
John Lewis Invictus Academy	4720	118	40
Benjamin E Mays High School	5840	146	40

Table 12 is a table with the individual school cost of diagnostic surveillance per week for staff for the Academic year 2021- 2022, assuming that 100% of the staff population are tested twice per week.

The third ABC analysis model examined student costs for the academic Fall 2022 semester to Mid Spring 2023 semester, and the results are shown in Figures 15, 16, and 17. The total number of weekly diagnostic tests estimated for the academic year for students was 2066 for the ten selected schools. This number was determined by adding the total number of students across the ten selected schools and multiplying by 35%. The ABC student model for August 2022 to February 2023, results showed the total cost per week for diagnostic testing at all ten schools was

$82,640. This estimate included the cost of tests and contractor time to conduct the rapid antigen testing at each individual school. The total cost per week for wastewater testing at all ten schools remained constant at $1,691. This estimate included the cost of collecting and analyzing samples, as well as personnel costs. On a per-school basis, the average weekly cost for diagnostic testing across ten schools during the second academic year (2022-2023) was $8,264 and individual school costs are shown in Figure 18 and Table 13. These estimates include the cost of the tests and contractor time to conduct the rapid antigen testing at each individual school. Wastewater testing on a per school basis remained the same at $169.10. The breakdown for per-student cost per week is the following: diagnostic testing comes out to $14 per student while the wastewater testing cost is $0.29. This is based on the total cost of diagnostic testing divided by the number of students enrolled at the 10 schools.

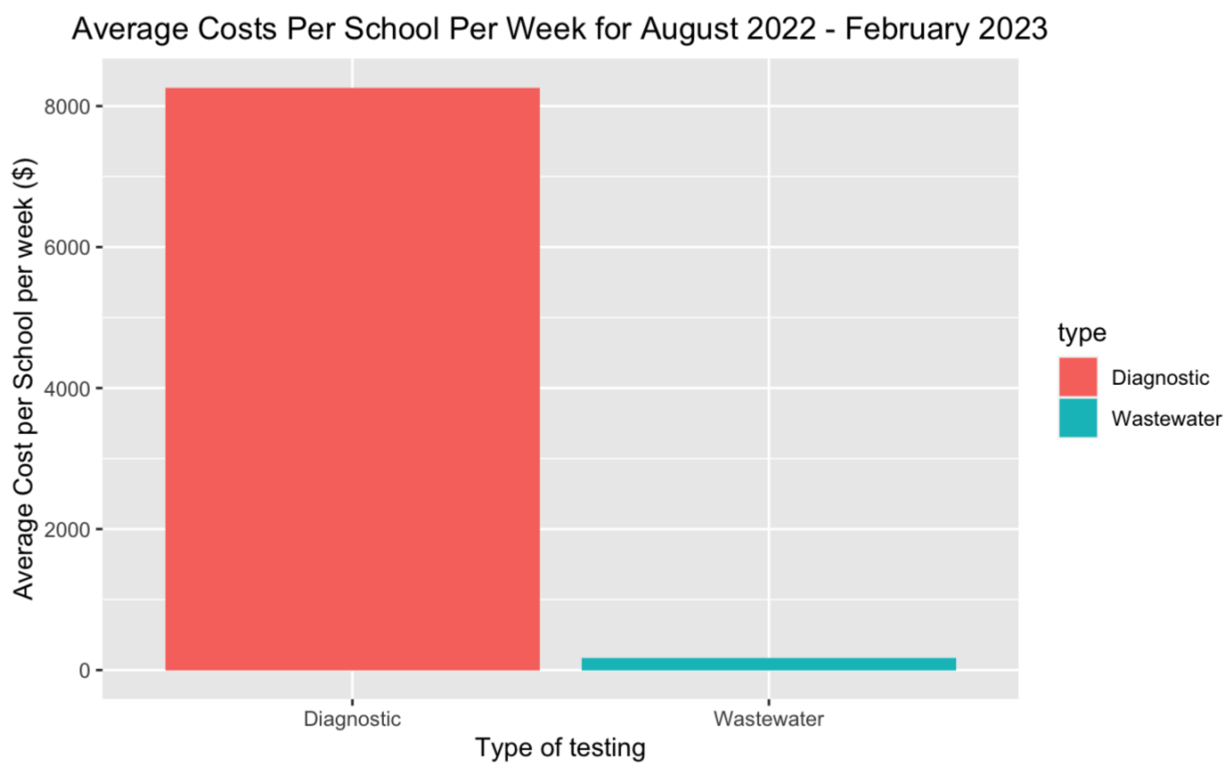

Figure 15 is a bar plot showing the average costs per school per week for diagnostic testing of students and wastewater surveillance for both staff and students from August 2022 – February 2023. The x-axis shows the type of surveillance approach, while the y-axis shows the average cost per school per week in US dollars.

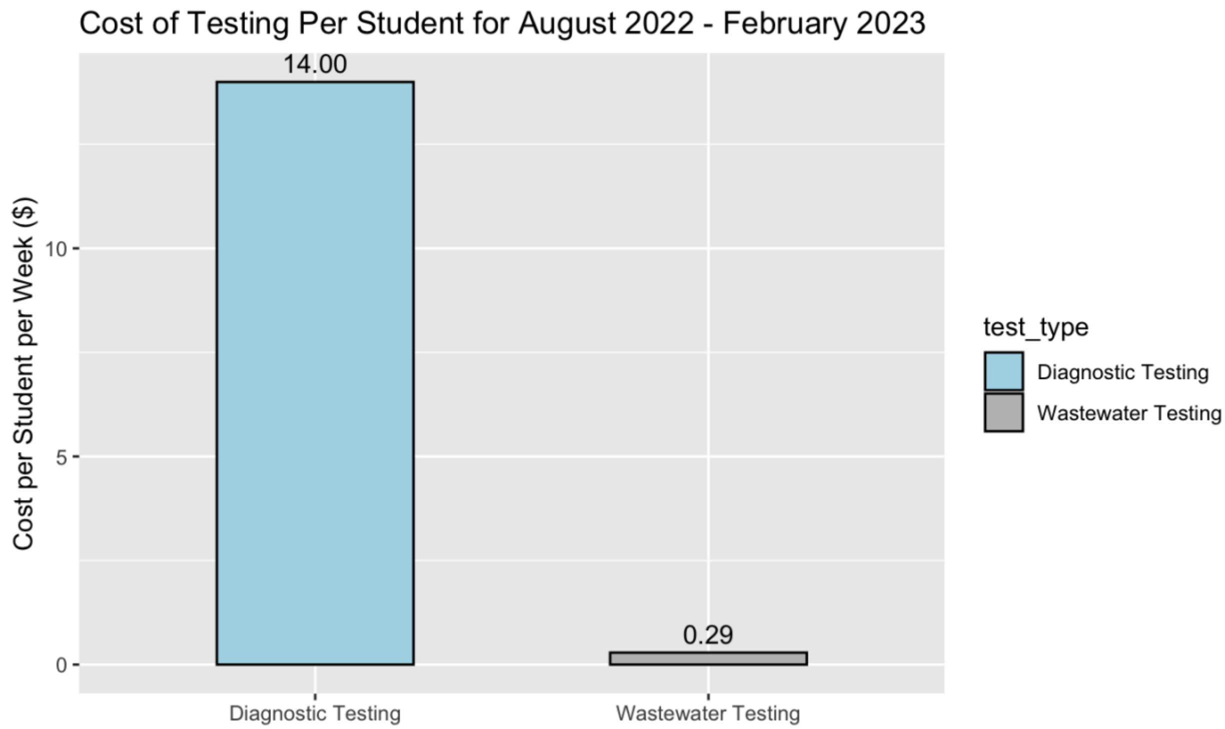

Figure 16 is a bar graph that displays the cost per student per week for diagnostic surveillance and wastewater monitoring from August 2022 – February 2023. The x-axis of the graph shows the two types of surveillance approaches: Diagnostic surveillance and Wastewater monitoring. The y-axis shows the cost per student per week in dollars.

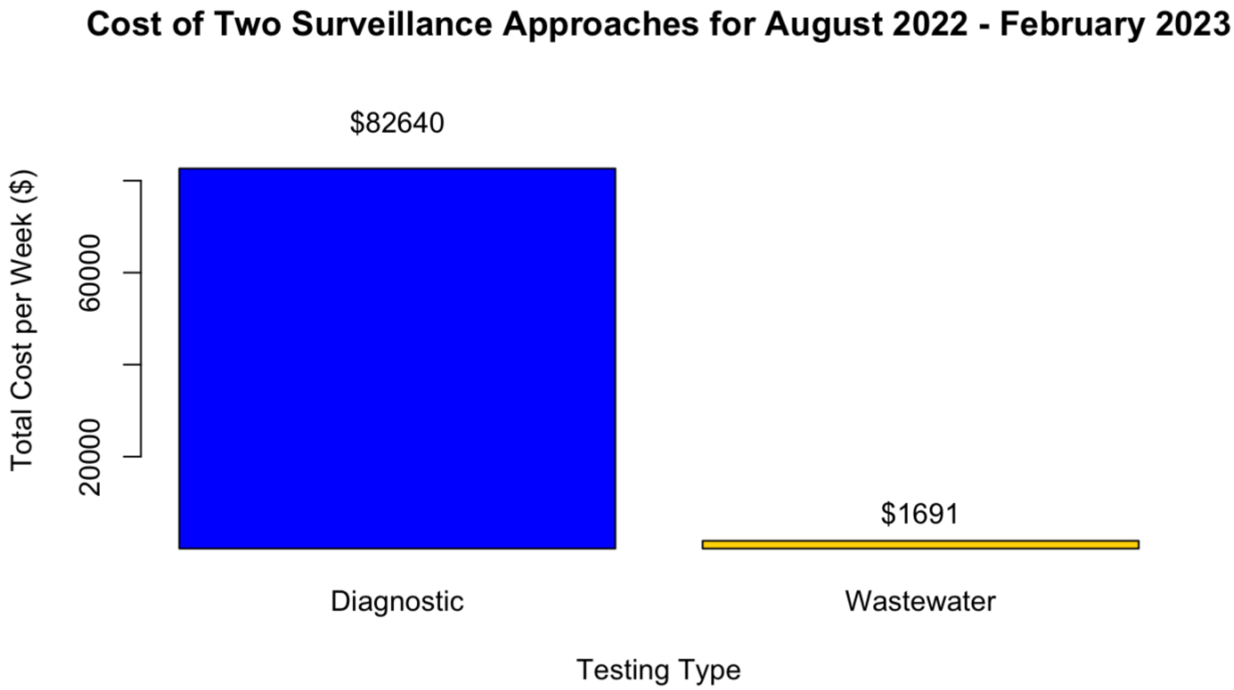

Figure 17 presents the total weekly cost for all ten study schools for two different surveillance approaches, in the 2022-2023 academic year (25 weeks, student diagnostic testing only).

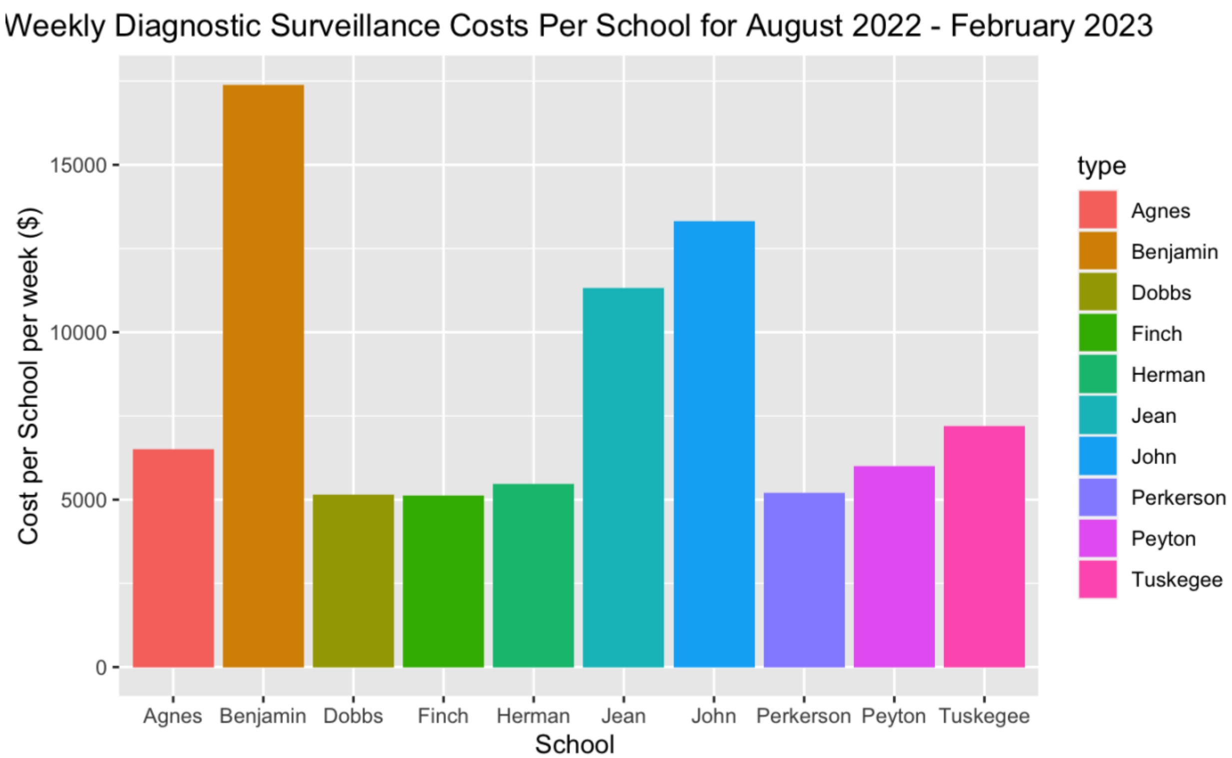

Figure 18 is a bar graph that visualizes the weekly cost per school for diagnostic testing of students. Individual school costs are listed in Table 9.

Study School	**Total cost for Diagnostic Surveillance Per Week ($)**	**Total Number of Students Enrolled**	**Cost of Diagnostic Surveillance Per Student ($)**
Tuskegee Airmen Global Academy	7200	514	14
Dobbs Elementary School	5160	368	14
Herman J. Russel West End Academy	5480	390	14
Perkerson Elementary School	5200	370	14
Finch Elementary	5120	366	14
Agnes Jones Elementary School	6520	465	14
Jean Childs Young Middle School	11320	809	14
Peyton Forest Elementary School	6000	428	14

John Lewis Invictus Academy	13320	950	14
Benjamin E Mays High School	17400	1244	14

Table 13 is a table with the individual school cost of diagnostic surveillance *per week for the Academic year 2022-2023 (25 weeks), assuming that 35% of the student population are tested twice per week.*

4.2 Sensitivity Analysis

To address uncertainty regarding the average cost of the two surveillance approaches in different scenarios, we ran a sensitivity analysis using a range of parameters. The study's simulated sensitivity analysis model estimated the cost per student associated with implementing diagnostic testing and wastewater monitoring considering a range of inflation rates and testing levels. The results of the sensitivity analysis are shown in Figures 19 and 20. Figure 19 displays the current non-inflated costs for both surveillance approaches. The results show that the median cost for routine wastewater monitoring is substantially lower than routine diagnostic testing. Additionally, results showed that in all cases the wastewater-based surveillance costs were lower than diagnostic surveillance. For diagnostic surveillance ,the model's results revealed that the minimum increase in cost per week assumed that 16% of all students enrolled are testing twice a week at all ten schools was $10.27, while for wastewater surveillance it was $0.45. The maximum increase in cost per student per week assumed that 84% of all students enrolled are testing at least 3 times a week at all ten school and factoring in ranging inflation rates for diagnostic surveillance was $52.69 per test and $4.45 per test for wastewater testing. These prices are how much each test would cost with increased testing and inflation. Figure 20 displays the inflated costs, and indicates that the median cost for both approaches increased.

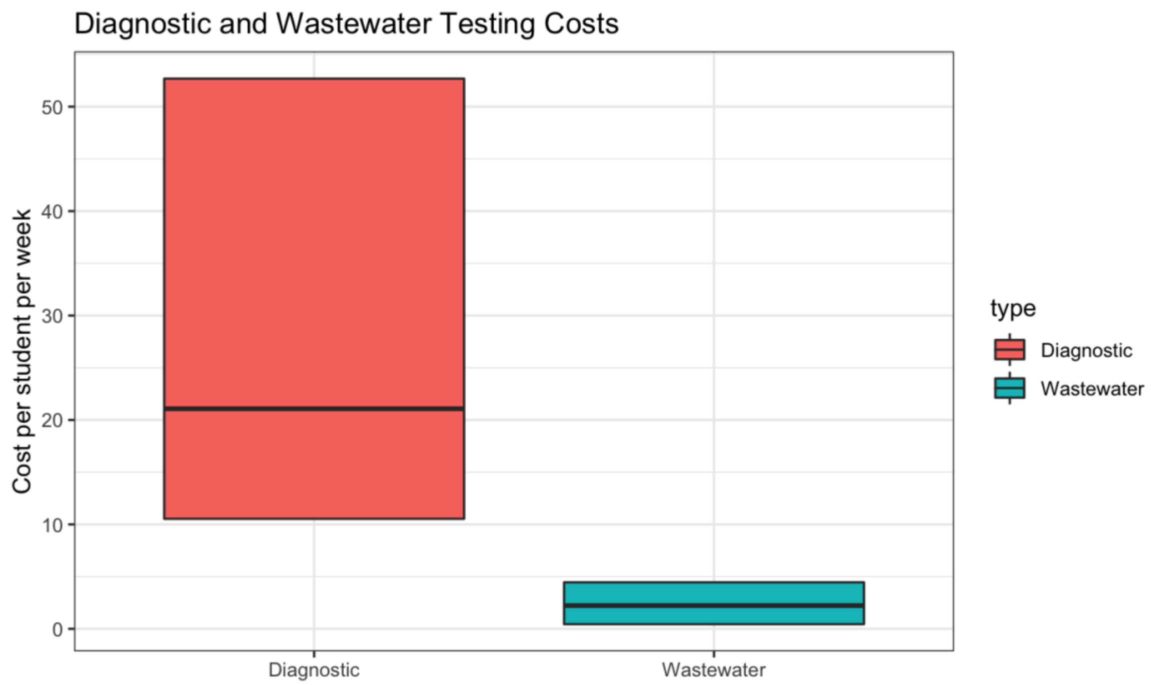

Figure 19 presents the actual non-inflated costs per student per week for diagnostic testing vs. wastewater monitoring.

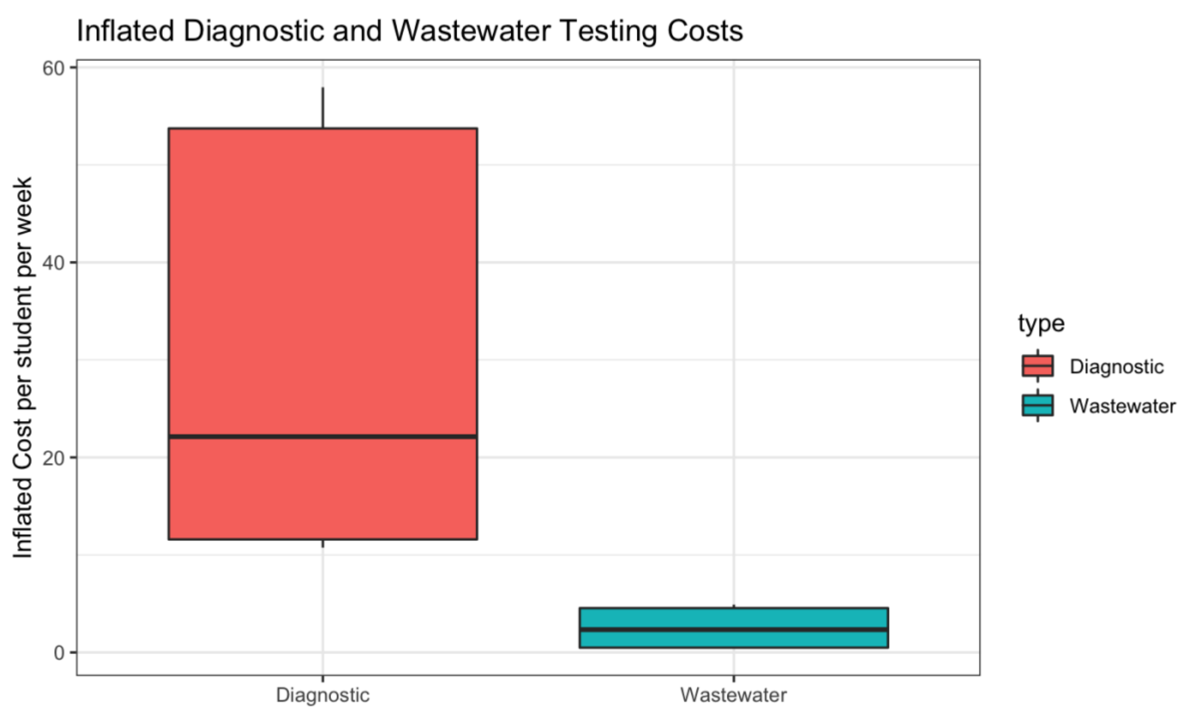

Figure 20 presents the inflated costs per student per week for diagnostic testing vs wastewater monitoring.

Chapter 5 Discussion and Recommendations

Our study presents novel findings about the financial costs associated with implementing diagnostic testing and wastewater monitoring as surveillance strategies for COVID-19 in K-12 communities. Our ABC and sensitivity analysis indicated that wastewater surveillance is a far less expensive alternative to rapid antigen diagnostic testing in Atlanta Public Schools. Furthermore, our results indicated that the cost of wastewater monitoring for SARS-CoV-2 remained consistent over time because it was not affected by the size of the school population, whereas the overall costs of rapid antigen diagnostic testing fluctuated due to a number of factors, including the number of tests being conducted, frequency of testing, and the size of individual selected schools. Our model analysis found that the cost of wastewater monitoring at the school-, student-, and staff- level compared to rapid antigen diagnostic testing was consistently more economical. We arrived at this conclusion by using both an ABC and sensitivity analysis with parameters that portrayed differing situations, such as participant willingness and inflation cost.

Children in K-12 communities children play a vital role in the transmission of respiratory illnesses, such as SARS-CoV-2, both within the school, and also to their families and wider community (Wolken et al., 2023). As the SARS-CoV-2 pandemic continues, communities across the nation have voiced concern over keeping themselves and their children healthy. In order to maintain safe and healthy school environments, it is crucial to have sensitive, comprehensive disease surveillance as well as effective mitigation measures. Other investigations have described wastewater monitoring as a cost effective and efficient approach to detect and quantify SARS-CoV-2 infections in communities (Castro-Gutierrez et al., 2022), (Fielding-Miller et al., 2023), and (Liu et al., 2022). Wastewater-based surveillance costs can offer valuable insight to key decision makers in school communities regarding potential mitigation strategies. Wastewater monitoring has been shown to identify trends and patterns in the prevalence of disease within communities (Harris-Lovett et al., 2021). And it has been shown that wastewater monitoring can detect the presence of pathogens, such as SARS-CoV-2 approximately 2 weeks before a surge of cases is reported (Liu et al., 2022). Stakeholders and decision makers at the school level can use the data provided by wastewater monitoring to identify areas of the school community most likely to be impacted and implement mitigation strategies, such as masking, social distancing, and disinfecting popular areas to reduce the transmission of disease.

The use of wastewater monitoring provides stakeholders an early warning system at a low cost that can help them make informed decisions to maintain safe and healthy communities. Target surveillance approaches such as rapid antigen diagnostic testing require participant buy in and as shown through each of our models is much more expensive to conduct. The key issue as mentioned before is identifying cases and reducing disease burden in communities, and the ability to so can often be hindered due to limited funding (*COVID-19 and Student Performance, Equity, and U.S. Education Policy*, n.d.). Moreover, communities in lower socioeconomic areas often do not have access or resources to maintain mitigation measures such increased availability of masks, extensive cleaning and disinfecting protocols, and air filtration systems (Gettings et al., 2021). Our study recognized this and conducted an extensive data collection and analysis process to find a sustainable alternative. Our study found that a viable alternative to diagnostic testing is wastewater -based surveillance. Wastewater monitoring is a surveillance approach that is flexible, sustainable, and feasible in terms of cost.

5.1 Overall comparison of results ABC

The results of the simulated ABC analysis models provided a detailed breakdown of the costs associated with implementing diagnostic testing and wastewater surveillance for the 2021-2022 academic year and time period of Fall 2022 to February 2023. Our study reports novel results that indicate the amount of funding required to implement comprehensive surveillance protocols in public schools. The results indicated that wastewater monitoring was considerably more cost effective than diagnostic testing as a surveillance approach for SARS-CoV-2 in Atlanta Public Schools. Our study results were consistent with the literature in proving wastewater monitoring is a low-cost tool for detecting pathogens, such as SARS-CoV-2 in communities. Additionally, findings from our study add information and evidence to the growing research on economic costs of surveillance approaches. Comparing the three models, it was evident that the costs associated with diagnostic testing were substantial compared to wastewater monitoring in terms of total cost estimates and implementation. All of the ABC models provided valuable findings about the costs associated with implementing two surveillance approaches in Atlanta Public schools. The most important finding from these models was that on average wastewater-based surveillance was the most cost- effective option. Our results provide information to Atlanta Public School and other stakeholders in K-12 communities on of two popular surveillance approaches used to detect disease. Stakeholders with limited funding can use these findings to prepare their budgets for the upcoming year to allocate resources. Also, being able to anticipate costs and prepare for them can increase the sustainability of whichever mitigation strategy they choose. While, Atlanta Public Schools can use our findings to decide on a surveillance approach with mitigation strategies for the upcoming and future academic years to reduce the transmission of disease. Additionally, if APS chooses to continue with wastewater monitoring as a surveillance approach, they can use our results to estimate costs for all schools in their school district and hire contractors such as BioBot and Concentric(companies that have experience in conducting wastewater surveillance) to set up and maintain monitoring.

5.1.2 Overall comparison of results Sensitivity Analysis

We wanted to take into consideration inflation factors that could impact the cost of supplies and resources for future studies or future implementation practices. Our study compared the difference in estimated costs to gain a better understanding of what impact inflation has on the cost of resources for each surveillance measure. As expected, the cost of supplies for both methods rose. The study results revealed that both surveillance approaches can vary considerably in cost, with the larger number of tests costing more and the smallest amount of test costing less. The sensitivity analysis parameters only considered number of tests and inflation rates which provided a reasonable range of costs. However, a caveat of this analysis is that it did not factor in all variables that could influence costs, such as gas, labor time and cost, and equipment. Despite, the limitations of the sensitivity analysis, the results indicated that regardless of varying parameters the cost for wastewater monitoring was less expensive. This analysis addressed a key potential question: as prices rise or fall which surveillance approach is most sustainable in terms of long-term costs and feasibility? This information is essential for stakeholders and community decision makers as they review budgets for the upcoming academic school year and allocate funding and resources for surveillance and mitigation measures.

5.2 Strengths of Wastewater Testing

Wastewater-based surveillance is a passive monitoring measure that can collect data and estimate the disease burden in a school or community without requiring community members to participate. Our study results indicated wastewater-based surveillance is a much less expensive option compared to mass testing using rapid antigen diagnostic testing kits. Wastewater-based surveillance has been used since the early 1990s to monitor infectious diseases such as cholera and poliomyelitis (Liu et al., 2022). This surveillance approach has been applied in various settings and has provided valuable information to communities, and guided polio vaccination strategies. Wastewater- based surveillance is a non-invasive approach that is cost-effective and can be used to measure the prevalence of multiple diseases, including asymptomatic and pre-symptomatic infections, in any chosen community (Georgia National Wastewater Surveillance System (GA NWSS), n.d.). Another benefit of wastewater monitoring is that a single sample can detect various pathogens. Additionally, wastewater monitoring is an inclusive approach that can detect pathogens circulating in the whole population not just populations that have access to diagnostic testing and choose to get tested. Although, wastewater monitoring is usually conducted at a municipal level by sample collection wastewater treatment plants, recent studies have demonstrated the application of this surveillance approach for colleges and universities. Some studies have shown that wastewater-based surveillance can detect an increase in SARS-CoV-2 presence or concentration up to two weeks before a surge in cases (Liu et al., 2022). This suggests that wastewater monitoring can serve as an early warning system for potential outbreaks before they are detected by diagnostic testing.

5.3 Strengths of Diagnostic Surveillance

Rapid antigen diagnostic testing has multiple strengths. This approach can identify individual cases. In our study, we assumed that 35-50% of students were getting tested twice weekly. Even though only a percentage of the student population was consistently getting tested, the benefits of rapid antigen diagnostic testing was extended to all students enrolled in each of these schools.

This is because even with a portion of the students testing, depending on the outcome of each of the individual results, it is possible to initiate contact tracing protocols and test exposed students to mitigate transmission. A benefit of this approach is the opportunity for a more targeted and rapid response to mitigate disease spread within the school community.

5.4 Limitations of these Surveillance Approaches

5.4.1 Wastewater Monitoring

Across all three models, we observed that the cost per student, per staff, and per school for wastewater-based surveillance remained constant. This suggests with the parameters chosen and used to estimate costs, there may be limited opportunities for additional cost savings. Also, this surveillance approach provides information on the overall community disease burden and not on individual cases of infection. Some limitations of wastewater monitoring at schools include: wastewater sample collection and processing typically requires about two days, samples only capture a snapshot in time of the school wastewater and the pathogens it contains, it is logistically difficult and expensive to set up auto-sampling devices that could take daily composite samples of wastewater, and infected students may not use the school toilets every day or at all. Finally, there is conflicting evidence about the sensitivity of wastewater monitoring to detect a single case of SARS-CoV-2 infection in a building (Liu et al., 2022).

5.4.2 Diagnostic Testing

Diagnostic testing is a more targeted surveillance approach and, in contrast to wastewater monitoring, provides rapid, specific identification of infected individuals. This allows the school nurses, teachers, and parents to take specific actions to move the infected child to a setting where they are less likely to transmit their infection to others and make sure that the child gets appropriate treatment. However, diagnostic testing can be more resource-intensive and may not provide the same early warning benefits as wastewater-based surveillance (Palladino et al., 2020). Additionally, diagnostic testing requires community buy in. If a large proportion of the students or staff refuse to participate, then the sensitivity of diagnostic testing as a surveillance approach will be greatly reduced (Fielding-Miller et al., 2023). It is also important to consider that testing individually requires time taken out of the school day to go and get tested. For example, if each school had 6,000 COVID-19 tests being taken each week and the test took 30 minutes to generate a result, the total time spent testing would be 3,000 hours. That is a considerable amount of time lost and highlights a limitation of implementation this approach in schools.

5.5 Strengths of this study

Our study has multiple strengths. Our results provide novel and accurate estimates on the cost of using wastewater monitoring due to comprehensive data provided by the Moe Research Team. The accuracy of wastewater monitoring costs allow stakeholders, such as APS to make informed decisions on choosing a surveillance strategy. Additionally, our data tables and results provide valuable insights into the resources of implementing wastewater surveillance in K-12 community. Furthermore, our collaboration with Atlanta Public School enhances the study's credibility and validity because our data from the school is provided by experts in the school community.

5.6 Additional considerations

The SARS- CoV-2 pandemic highlighted the need for surveillance measures to assess the burden of disease in school communities. Our study examined which surveillance approach was most cost effective, feasible, and sustainable. Initially, our study focused on ten schools, but as our research study evolved, the Moe Research Team added three more schools to the weekly sample collection routine and started monitoring for three additional target pathogens in the wastewater samples. Pathogens added were: Influenza A, Influenza B, and Respiratory Syncytial Virus (RSV). The addition of these pathogen targets at little additional cost demonstrates the flexibility of wastewater monitoring and the possible economy of scale for expanding the panel of target pathogens and achieving a more comprehensive disease surveillance program.

Each of the two surveillance approaches has strengths and limitations, and it is not necessary to choose one over the other. K-12 communities can use a mix of both approached to identify cases and reduce the transmission of disease. Diagnostic testing covers individuals who choose to get tested, while wastewater monitoring only covers individuals that use the bathroom at school. Therefore, if stakeholders choose to use a combination of both approaches, it can provide detailed information on infection trends in the school population and help maintain a safe and healthy environment.

5.7 Limitations

The cost estimates for both surveillance approaches are based on simulated models using data from urban schools in Atlanta, Georgia and may not be generalizable to rural areas or settings outside of Georgia .

In all of our models we did not include the capital investment and maintenance costs for the laboratory equipment used for the wastewater analyses. In this study, the laboratory already had the necessary equipment and was using it to analyze a large number of wastewater samples for multiple studies. However, another laboratory, such as a state public health lab or commercial lab, may need to charge an equipment service fee as part of the costs of wastewater monitoring.

Additionally, we were unable to get detailed cost information from the GADPH, Viral Solutions, and APS for some parameters in the models. We assumed that the per-test cost of rapid diagnostic testing included contractor labor and that there was no additional fee per school visit.

We were not able to get information on the actual number of students who participated in the voluntary diagnostic testing program in the ten study schools. Based on discussion with APS and media reports, we assumed a constant proportion of 50% student participation in the 2021-2022 academic year and a 35% proportion of student participation in the 2022-2023 academic year and a testing frequency of twice a week -as was offered by the contractor. We also assumed 100% compliance by the APS staff with the twice weekly diagnostic testing requirement. However, the actual proportions of students and staff who participated in the testing program and the frequency that they were tested may have varied substantially over time depending on personal, school, and community factors. Therefore, the costs of the diagnostic testing may have been over- or underestimated.

Finally, this study focused on analyzing the cost of these two surveillance approaches and did not attempt to compare the sensitivity of these two approaches or the concordance between the surveillance results.

Chapter 6 Conclusion

In conclusion, the simulated ABC analysis models provide a useful framework for evaluating the costs of implementing COVID-19 surveillance in schools by two different approaches. As schools and decision-makers consider which approach to implement for the upcoming academic year, the findings from this study can provide valuable information on the costs of two surveillance approaches and the determinants of those costs. However, as all school systems have different resources, enabling factors and barriers, each should consider their resources and needs when deciding on a surveillance strategy to ensure the most effective use of available funds.

References

A Cost-Benefit Analysis of Physical Activity Using Bike/Pedestrian Trails—Guijing Wang, Caroline A. Macera, Barbara Scudder-Soucie, Tom Schmid, Michael Pratt, David Buchner, 2005. (n.d.). Retrieved February 14, 2023, from https://journals.sagepub.com/doi/abs/10.1177/1524839903260687

Amy, J. (n.d.). *Back-to-school photo shows unmasked students crowding shoulder-to-shoulder in Georgia*. USA TODAY. Retrieved March 24, 2023, from https://www.usatoday.com/story/news/education/2020/08/05/back-school-photos-kids-without-masks-no-social-distancing-georgia/3297372001/

An opinion on Wastewater-Based Epidemiological Monitoring (WBEM) with Clinical Diagnostic Test (CDT) for detecting high-prevalence areas of community COVID-19 infections—ScienceDirect. (n.d.). Retrieved April 16, 2023, from https://www.sciencedirect.com/science/article/pii/S246858442200071X#bib2

APS surveillance testing reduces spread of COVID-19 – the Southerner Online. (n.d.). Retrieved April 17, 2023, from https://thesoutherneronline.com/82144/news/aps-surveillance-testing-reduces-spread-of-covid-19/

Assessment of a Program for SARS-CoV-2 Screening and Environmental Monitoring in an Urban Public School District | Infectious Diseases | JAMA Network Open | JAMA Network. (n.d.). Retrieved February 14, 2023, from https://jamanetwork.com/journals/jamanetworkopen/article-abstract/2784428

Atlanta Public Schools aims to test thousands weekly for COVID-19. (n.d.). Retrieved April 17, 2023, from https://www.ajc.com/news/atlanta-news/atlanta-public-schools-aims-to-test-thousands-weekly-for-covid-19/SGVNIPIWKZCSNM2MIYZWXE4ZF4/

Barker, J., Stevens, D., & Bloomfield, S. F. (2001). Spread and prevention of some common viral infections in community facilities and domestic homes. *Journal of Applied Microbiology*, *91*(1), 7–21. https://doi.org/10.1046/j.1365-2672.2001.01364.x

Barrera, C. M., Hazell, M., Chamberlain, A. T., Gandhi, N. R., Onwubiko, U., Liu, C. Y., Prieto, J., Khan, F., & Shah, S. (2021). Retrospective cohort study of COVID-19 among children in Fulton County, Georgia, March 2020–June 2021. *BMJ Paediatrics Open*, *5*(1), e001223. https://doi.org/10.1136/bmjpo-2021-001223

Boehmer, T. K., DeVies, J., Caruso, E., van Santen, K. L., Tang, S., Black, C. L., Hartnett, K. P., Kite-Powell, A., Dietz, S., Lozier, M., & Gundlapalli, A. V. (2020). Changing Age Distribution of the COVID-19 Pandemic—United States, May–August 2020. *Morbidity and Mortality Weekly Report*, *69*(39), 1404–1409. https://doi.org/10.15585/mmwr.mm6939e1

Bureau, U. C. (n.d.). *2018 Public Elementary-Secondary Education Finance Data*. Census.Gov. Retrieved February 10, 2023, from https://www.census.gov/data/tables/2018/econ/school-finances/secondary-education-finance.html

Budgeting for Environmental Health Services in Healthcare Facilities: A Ten-Step Model for Planning and Costing—PMC. (n.d.). Retrieved February 10, 2023, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7143484/

Cai, J., Sun, W., Huang, J., Gamber, M., Wu, J., & He, G. (2020). Indirect Virus Transmission in Cluster of COVID-19 Cases, Wenzhou, China, 2020. *Emerging Infectious Diseases*, *26*(6), 1343–1345. https://doi.org/10.3201/eid2606.200412

Campbell, D., Edwards, B., Milat |, A., Thackway, S., Whittaker, E., Goudswaard, L., Cretikos, M., Penna, A., & Chant, K. (2021). NSW Health COVID-19 Emergency Response Priority Research program: A case study of rapid translation of research into health decision making. *Public Health Research & Practice*, *31*(4). https://doi.org/10.17061/phrp3142124

Castro-Gutierrez, V., Hassard, F., Vu, M., Leitao, R., Burczynska, B., Wildeboer, D., Stanton, I., Rahimzadeh, S., Baio, G., Garelick, H., Hofman, J., Kasprzyk-Hordern, B., Kwiatkowska, R., Majeed, A., Priest, S., Grimsley, J., Lundy, L., Singer, A. C., & Di Cesare, M. (2022). Monitoring occurrence of SARS-CoV-2 in school populations: A wastewater-based approach. *PLoS ONE*, *17*(6), e0270168. https://doi.org/10.1371/journal.pone.0270168

CDC. (2020, February 11). *COVID-19 and Your Health*. Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/testing.html

CDC. (2020, March 28). *COVID Data Tracker*. Centers for Disease Control and Prevention. https://covid.cdc.gov/covid-data-tracker

CDC. (2023, March 15). *CDC Museum COVID-19 Timeline*. Centers for Disease Control and Prevention. https://www.cdc.gov/museum/timeline/covid19.html

Children and COVID-19 Vaccination Trends. (n.d.). Retrieved February 10, 2023, from https://www.aap.org/en/pages/2019-novel-coronavirus-covid-19-infections/children-and-covid-19-vaccination-trends/

Children and COVID-19: State-Level Data Report. (n.d.). Retrieved April 15, 2023, from https://www.aap.org/en/pages/2019-novel-coronavirus-covid-19-infections/children-and-covid-19-state-level-data-report/

COVID-19 and student performance, equity, and U.S. education policy: Lessons from pre-pandemic research to inform relief, recovery, and rebuilding. (n.d.). Economic Policy Institute. Retrieved April 18, 2023, from https://www.epi.org/publication/the-consequences-of-the-covid-19-

pandemic-for-education-performance-and-equity-in-the-united-states-what-can-we-learn-from-pre-pandemic-research-to-inform-relief-recovery-and-rebuilding/

COVID-19 Guidance for Safe Schools and Promotion of In-Person Learning. (n.d.). Retrieved April 16, 2023, from https://www.aap.org/en/pages/2019-novel-coronavirus-covid-19-infections/clinical-guidance/covid-19-planning-considerations-return-to-in-person-education-in-schools/

Covid-19 Vaccine Dashboard. (n.d.). Retrieved April 15, 2023, from https://experience.arcgis.com/experience/3d8eea39f5c1443db1743a4cb8948a9c

COVID-19 cases climb among young people; Metro Atlanta teen shares her story. (2021, August 5). 11Alive.Com. https://www.11alive.com/article/news/health/coronavirus/covid-kids-georgia/85-4fcef094-e508-46be-8b53-3ebdfd62788a

COVID-19 Surveillance Testing Schedule (Effective 08/01/2022) . (2022, August 1). *COVID-19 Surveillance Testing Schedule*. Retrieved February 2, 2023, from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.atlantapublicschools.us/cms/lib/GA01000924/Centricity/Domain/16897/APS%20Fall%202022%20Surveillance%20Testing%20Schedule%2007.27.2022.pdf.

Covid-19 Vaccine Dashboard. (n.d.). Retrieved April 15, 2023, from https://experience.arcgis.com/experience/3d8eea39f5c1443db1743a4cb8948a9c

COVID-19 is a leading cause of death in children and young people in the US | University of Oxford. (2023, January 31). https://www.ox.ac.uk/news/2023-01-31-covid-19-leading-cause-death-children-and-young-people-us

Donaldson, A. L., Harris, J. P., Vivancos, R., & O'Brien, S. J. (n.d.). Risk factors associated with outbreaks of seasonal infectious disease in school settings, England, UK. *Epidemiology and Infection*, *148*, e287. https://doi.org/10.1017/S0950268820002824

Dong, Y., Mo, X., Hu, Y., Qi, X., Jiang, F., Jiang, Z., & Tong, S. (2020). Epidemiology of COVID-19 Among Children in China. *Pediatrics*, *145*(6), e20200702. https://doi.org/10.1542/peds.2020-0702

Durry, S. (2023, April 3). Virial solutions cost estimate per test . personal.

Eldridge, E. (2020, July 20). *Percentage Of Children Infected With COVID-19 Has Tripled In Georgia*. Georgia Public Broadcasting. https://www.gpb.org/news/2020/07/20/percentage-of-children-infected-covid-19-has-tripled-in-georgia

Endo, A., Uchida, M., Hayashi, N., Liu, Y., Atkins, K. E., Kucharski, A. J., & Funk, S. (2021). Within and between classroom transmission patterns of seasonal influenza among primary school students in Matsumoto city, Japan. *Proceedings of the National Academy of Sciences*, *118*(46), e2112605118. https://doi.org/10.1073/pnas.2112605118

Expanded Testing For COVID-19 In Georgia. (2020, April 15). Georgia Department of Public Health. https://dph.georgia.gov/press-releases/2020-04-15/expanded-testing-covid-19-georgia

Feng, G., Zhang, L., Wang, K., Chen, B., & Xia, H. H.-X. (2021). Research, Development and Application of COVID-19 Vaccines: Progress, Challenges, and Prospects. *Journal of Exploratory Research in Pharmacology*, *6*(2), 31–43. https://doi.org/10.14218/JERP.2021.00004

Fielding-Miller, R., Karthikeyan, S., Gaines, T., Garfein, R. S., Salido, R. A., Cantu, V. J., Kohn, L., Martin, N. K., Wynn, A., Wijaya, C., Flores, M., Omaleki, V., Majnoonian, A., Gonzalez-Zuniga, P., Nguyen, M., Vo, A. V., Le, T., Duong, D., Hassani, A., … Knight, R. (2023). Wastewater and surface monitoring to detect COVID-19 in elementary school settings: The Safer at School Early Alert project. *MedRxiv*, 2021.10.19.21265226. https://doi.org/10.1101/2021.10.19.21265226

Flasche, S., & Edmunds, W. J. (2021). The role of schools and school-aged children in SARS-CoV-2 transmission. *The Lancet Infectious Diseases*, *21*(3), 298–299. https://doi.org/10.1016/S1473-3099(20)30927-0

Gaythorpe, K. A. M., Bhatia, S., Mangal, T., Unwin, H. J. T., Imai, N., Cuomo-Dannenburg, G., Walters, C. E., Jauneikaite, E., Bayley, H., Kont, M. D., Mousa, A., Whittles, L. K., Riley, S., & Ferguson, N. M. (2021). Children's role in the COVID-19 pandemic: A systematic review of early surveillance data on susceptibility, severity, and transmissibility. *Scientific Reports*, *11*(1), 13903. https://doi.org/10.1038/s41598-021-92500-9

Georgia Coronavirus Map and Case Count—The New York Times. (n.d.). Retrieved February 10, 2023, from https://www.nytimes.com/interactive/2021/us/georgia-covid-cases.html

Georgia Department of Public Health, Office of Health Indicators for Planning—OASIS. (n.d.). Retrieved February 10, 2023, from https://oasis.state.ga.us/trendingtool/index.html?redirectto=CountyPop

Georgia National Wastewater Surveillance System (GA NWSS). (n.d.). Georgia Department of Public Health. Retrieved February 10, 2023, from https://dph.georgia.gov/epidemiology/acute-disease-epidemiology/georgia-national-wastewater-surveillance-system-ga-nwss

Gettings, J., Czarnik, M., Morris, E., Haller, E., Thompson-Paul, A. M., Rasberry, C., Lanzieri, T. M., Smith-Grant, J., Aholou, T. M., Thomas, E., Drenzek, C., & MacKellar, D. (2021). Mask Use and Ventilation Improvements to Reduce COVID-19 Incidence in Elementary Schools—Georgia, November 16–December 11, 2020. *Morbidity and Mortality Weekly Report*, *70*(21), 779–784. https://doi.org/10.15585/mmwr.mm7021e1

González López-Valcárcel, B., & Vallejo-Torres, L. (2021). The costs of COVID-19 and the cost-effectiveness of testing. *Applied Economic Analysis*, *29*(85), 77–89. https://doi.org/10.1108/AEA-11-2020-0162

Gov. Kemp, Officials Confirm Two Cases of COVID-19 in Georgia. (2020, March 2). Georgia Department of Public Health. https://dph.georgia.gov/press-releases/2020-03-02/gov-kemp-officials-confirm-two-cases-covid-19-georgia

Hammond, A., Khalid, T., Thornton, H. V., Woodall, C. A., & Hay, A. D. (2021). Should homes and workplaces purchase portable air filters to reduce the transmission of SARS-CoV-2 and other respiratory infections? A systematic review. *PLOS ONE*, *16*(4), e0251049. https://doi.org/10.1371/journal.pone.0251049

Harris-Lovett, S., Nelson, K. L., Beamer, P., Bischel, H. N., Bivins, A., Bruder, A., Butler, C., Camenisch, T. D., De Long, S. K., Karthikeyan, S., Larsen, D. A., Meierdiercks, K., Mouser, P. J., Pagsuyoin, S., Prasek, S. M., Radniecki, T. S., Ram, J. L., Roper, D. K., Safford, H., … Korfmacher, K. S. (2021). Wastewater Surveillance for SARS-CoV-2 on College Campuses: Initial Efforts, Lessons Learned, and Research Needs. *International Journal of Environmental Research and Public Health*, *18*(9), 4455. https://doi.org/10.3390/ijerph18094455

Hart, O. E., & Halden, R. U. (2020). Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: Feasibility, economy, opportunities and challenges. *Science of The Total Environment*, *730*, 138875. https://doi.org/10.1016/j.scitotenv.2020.138875

Healthcare Activity-Based Costing: A COVID-19 Must-Have. (2020, June 16). https://www.healthcatalyst.com/insights/healthcare-activity-based-costing-covid-19-must-have

How to Prioritize the Health and Safety of Students, School Personnel, and Families | U.S. Department of Education. (n.d.). Retrieved April 16, 2023, from https://sites.ed.gov/backtoschool/health-safety/

Implementation of a pooled surveillance testing program for asymptomatic SARS-CoV-2 infections in K-12 schools and universities—ScienceDirect. (n.d.). Retrieved February 14, 2023, from https://www.sciencedirect.com/science/article/pii/S2589537021003084

Islam, A., Hossen, F., Rahman, A., Sultana, K. F., Hasan, M. N., Haque, A., Sosa-Hernández, J. E., Oyervides-Muñoz, M. A., Parra-Saldívar, R., Ahmed, T., Islam, T., Dhama, K., Sangkham, S., Bahadur, N. M., Reza, H. M., Jakariya, Al Marzan, A., Bhattacharya, P., Sonne, C., & Ahmed, F. (2022). An opinion on Wastewater-Based Epidemiological Monitoring (WBEM) with Clinical Diagnostic Test (CDT) for detecting high-prevalence areas of community COVID-19 Infections. *Current Opinion in Environmental Science & Health*, 100396. https://doi.org/10.1016/j.coesh.2022.100396

Ismail, S. A., Saliba, V., Lopez Bernal, J., Ramsay, M. E., & Ladhani, S. N. (2021). SARS-CoV-2 infection and transmission in educational settings: A prospective, cross-sectional analysis of infection clusters and outbreaks in England. *The Lancet Infectious Diseases*, *21*(3), 344–353. https://doi.org/10.1016/S1473-3099(20)30882-3

K-12 State Reopening Plans · The Hunt Institute. (n.d.). The Hunt Institute. Retrieved April 16, 2023, from https://hunt-institute.org/covid-19-resources/k-12-reopening-plans-by-state/

Kennedy, M. (2020, June 10). *Reopening means an additional $1.8 million in costs for average-sized school district, administrators estimate*. American School & University. https://www.asumag.com/covid-19/article/21133640/reopening-means-an-additional-18-million-in-costs-for-averagesized-school-district-administrators-estimate

Kliff, S., & Sanger-Katz, M. (2020, September 8). It's Not Easy to Get a Coronavirus Test for a Child. *The New York Times*. https://www.nytimes.com/2020/09/08/upshot/children-testing-shortfalls-virus.html

Lambert-Niclot, S., Cuffel, A., Le Pape, S., Vauloup-Fellous, C., Morand-Joubert, L., Roque-Afonso, A.-M., Le Goff, J., Delaugerre, C., & on behalf of the AP-HP/Universities/INSERMCOVID-19 Research Collaboration. (2020). Evaluation of a Rapid Diagnostic Assay for Detection of SARS-CoV-2 Antigen in Nasopharyngeal Swabs. *Journal of Clinical Microbiology*, *58*(8), e00977-20. https://doi.org/10.1128/JCM.00977-20

LaTurner, Z. W., Zong, D. M., Kalvapalle, P., Gamas, K. R., Terwilliger, A., Crosby, T., Ali, P., Avadhanula, V., Santos, H. H., Weesner, K., Hopkins, L., Piedra, P. A., Maresso, A. W., & Stadler, L. B. (2021). Evaluating recovery, cost, and throughput of different concentration methods for SARS-CoV-2 wastewater-based epidemiology. *Water Research*, *197*, 117043. https://doi.org/10.1016/j.watres.2021.117043

Leidman, E., Duca, L. M., Omura, J. D., Proia, K., Stephens, J. W., & Sauber-Schatz, E. K. (2021). COVID-19 Trends Among Persons Aged 0–24 Years—United States, March 1–December 12, 2020. *Morbidity and Mortality Weekly Report*, *70*(3), 88–94. https://doi.org/10.15585/mmwr.mm7003e1

Liu, P., Ibaraki, M., VanTassell, J., Geith, K., Cavallo, M., Kann, R., Guo, L., & Moe, C. L. (2022). A sensitive, simple, and low-cost method for COVID-19 wastewater surveillance at an institutional level. *The Science of the Total Environment*, *807*(Pt 3), 151047. https://doi.org/10.1016/j.scitotenv.2021.151047

Management and control of communicable diseases in schools and other child care settings: Systematic review on the incubation period and period of infectiousness | BMC Infectious

Diseases | Full Text. (n.d.). Retrieved April 18, 2023, from https://bmcinfectdis.biomedcentral.com/articles/10.1186/s12879-018-3095-8

Mask Use and Ventilation Improvements to Reduce COVID-19 Incidence in Elementary Schools—Georgia, November 16–December 11, 2020—PMC. (n.d.). Retrieved April 20, 2023, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8158891/

McClary-Gutierrez, J. S., Mattioli, M. C., Marcenac, P., Silverman, A. I., Boehm, A. B., Bibby, K., Balliet, M., de los Reyes, F. L., Gerrity, D., Griffith, J. F., Holden, P. A., Katehis, D., Kester, G., LaCross, N., Lipp, E. K., Meiman, J., Noble, R. T., Brossard, D., & McLellan, S. L. (2021). SARS-CoV-2 Wastewater Surveillance for Public Health Action. *Emerging Infectious Diseases*, *27*(9), e210753. https://doi.org/10.3201/eid2709.210753

Medema, G., Heijnen, L., Elsinga, G., Italiaander, R., & Brouwer, A. (2020). Presence of SARS-Coronavirus-2 RNA in Sewage and Correlation with Reported COVID-19 Prevalence in the Early Stage of the Epidemic in The Netherlands. *Environmental Science & Technology Letters*, acs.estlett.0c00357. https://doi.org/10.1021/acs.estlett.0c00357

Michaud, M., & Dietz, I. C. (2023). The effects of the SARS-CoV-2 pandemic on children and youth with special health care needs. *Frontiers in Pediatrics*, *10*. https://www.frontiersin.org/articles/10.3389/fped.2022.1007770

Oh, C., Zhou, A., O'Brien, K., Jamal, Y., Wennerdahl, H., Schmidt, A. R., Shisler, J. L., Jutla, A., Schmidt, A. R., Keefer, L., Brown, W. M., & Nguyen, T. H. (2022). Application of neighborhood-scale wastewater-based epidemiology in low COVID-19 incidence situations. *Science of The Total Environment*, *852*, 158448. https://doi.org/10.1016/j.scitotenv.2022.158448

Park, Y. J., Choe, Y. J., Park, O., Park, S. Y., Kim, Y.-M., Kim, J., Kweon, S., Woo, Y., Gwack, J., Kim, S. S., Lee, J., Hyun, J., Ryu, B., Jang, Y. S., Kim, H., Shin, S. H., Yi, S., Lee, S., Kim, H.

K., … Jeong, E. K. (2020). Contact Tracing during Coronavirus Disease Outbreak, South Korea, 2020. *Emerging Infectious Diseases*, *26*(10), 2465–2468. https://doi.org/10.3201/eid2610.201315

Pavilonis, B., Ierardi, A. M., Levine, L., Mirer, F., & Kelvin, E. A. (2021). Estimating aerosol transmission risk of SARS-CoV-2 in New York City public schools during reopening. *Environmental Research*, *195*, 110805. https://doi.org/10.1016/j.envres.2021.110805

Poline, J., Gaschignard, J., Leblanc, C., Madhi, F., Foucaud, E., Nattes, E., Faye, A., Bonacorsi, S., Mariani, P., Varon, E., Smati-Lafarge, M., Caseris, M., Basmaci, R., Lachaume, N., & Ouldali, N. (2021). Systematic Severe Acute Respiratory Syndrome Coronavirus 2 Screening at Hospital Admission in Children: A French Prospective Multicenter Study. *Clinical Infectious Diseases*, *72*(12), 2215–2217. https://doi.org/10.1093/cid/ciaa1044

Public Schools, A. (2021, August 1). Mandatory COVID Surveillance for all staff FAQ. Atlanta ; Atlanta Public Schools.

R: The R Project for Statistical Computing. (n.d.). Retrieved April 20, 2023, from https://www.r-project.org/

Return to school is driving up Covid-19 cases in kids, but there are more tools to keep them safe this year | CNN. (n.d.). Retrieved March 24, 2023, from https://www.cnn.com/2022/09/08/health/covid-kids-back-to-school/index.html

RStudio Desktop—Posit. (n.d.). Retrieved April 20, 2023, from https://posit.co/download/rstudio-desktop/

Safford, H. R., Shapiro, K., & Bischel, H. N. (2022). Wastewater analysis can be a powerful public health tool—If it's done sensibly. *Proceedings of the National Academy of Sciences*, *119*(6), e2119600119. https://doi.org/10.1073/pnas.2119600119

School Opening Tracker. (n.d.). Retrieved April 16, 2023, from https://about.burbio.com/school-opening-tracker

School responses in Georgia to the coronavirus (COVID-19) pandemic. (n.d.). Ballotpedia. Retrieved April 16, 2023, from https://ballotpedia.org/School_responses_in_Georgia_to_the_coronavirus_(COVID-19)_pandemic

Something old, something new, something borrowed, something blue: A framework for the marriage of health econometrics and cost-effectiveness analysis—Hoch—2002—Health Economics—Wiley Online Library. (n.d.). Retrieved February 14, 2023, from https://onlinelibrary.wiley.com/doi/abs/10.1002/hec.678?casa_token=fSZViDl4U28AAAAA:jX0VG2BYn8kqF1bkJYz9rewtLKCZJGepfHUWGXBrSKPK_XhpbyE-ZBAI6NN1FDbCiLJ5QuM5H3Rdww

Sonnad-Joshi, A. (n.d.). APS surveillance testing reduces spread of COVID-19. *The Southerner Online*. Retrieved April 10, 2023, from https://thesoutherneronline.com/82144/news/aps-surveillance-testing-reduces-spread-of-covid-19/

Study sheds light on SARS-CoV-2 transmission in homes with kids. (2023, January 17). American Medical Association. https://www.ama-assn.org/delivering-care/public-health/study-sheds-light-sars-cov-2-transmission-homes-kids

Supporting Students During the COVID-19 Pandemic: Maximizing In-Person Learning and Implementing Effective Practices for Students in Quarantine and Isolation | U.S. Department of Education. (n.d.). Retrieved February 10, 2023, from https://www.ed.gov/coronavirus/supporting-students-during-covid-19-pandemic

Surveillance Testing in School / Surveillance Testing. (n.d.). Retrieved March 25, 2023, from https://www.atlantapublicschools.us/domain/http%3A%2F%2Fwww.atlantapublicschools.us%2Fsite%2Fdefault.aspx%3FDomainID%3D16130

Survey shows Texas educators do not feel safe at schools, overwhelmingly support mask mandates and rapid testing for Covid-19. (2022, January 27). Texas AFT. https://www.texasaft.org/releases/survey-shows-texas-educators-do-not-feel-safe-at-schools-overwhelmingly-support-mask-mandates-and-rapid-testing-for-covid-19/

Tabatadze, S., & Chachkhiani, K. (2021). COVID-19 and Emergency Remote Teaching in the Country of Georgia: Catalyst for Educational Change and Reforms in Georgia? *Educational Studies*, *57*(1), 78–95. https://doi.org/10.1080/00131946.2020.1863806

Testing for COVID-19 at School: Frequently Asked Questions. (n.d.). Retrieved February 14, 2023, from https://www.edweek.org/leadership/should-schools-test-students-and-staff-for-covid-19/2021/03

Tromberg, B. J., Schwetz, T. A., Pérez-Stable, E. J., Hodes, R. J., Woychik, R. P., Bright, R. A., Fleurence, R. L., & Collins, F. S. (2020). Rapid Scaling Up of Covid-19 Diagnostic Testing in the United States—The NIH RADx Initiative. *New England Journal of Medicine*, *383*(11), 1071–1077. https://doi.org/10.1056/NEJMsr2022263

Tupper, P., & Colijn, C. (2021). COVID-19 in schools: Mitigating classroom clusters in the context of variable transmission. *PLOS Computational Biology*, *17*(7), e1009120. https://doi.org/10.1371/journal.pcbi.1009120

Updates + Alerts / Self-Report+ Weekly Case Report. (n.d.). Retrieved February 10, 2023, from https://www.atlantapublicschools.us/Page/http%3A%2F%2Fwww.atlantapublicschools.us%2Fsite%2Fdefault.aspx%3FPageID%3D64958

Updates + Alerts / Self-Report+ Weekly Case Report. (n.d.). Retrieved April 18, 2023, from https://www.atlantapublicschools.us/Page/http%3A%2F%2Fwww.atlantapublicschools.us%2Fsite%2Fdefault.aspx%3FPageID%3D64958

Wang, L., Chu, C., Yang, G., Hao, R., Li, Z., Cao, Z., Qiu, S., Li, P., Wu, Z., Yuan, Z., Xu, Y., Zeng, D., Wang, Y., & Song, H. (2014). Transmission characteristics of different students during a school outbreak of (H1N1) pdm09 influenza in China, 2009. *Scientific Reports*, *4*, 5982. https://doi.org/10.1038/srep05982

Wolken, M., Sun, T., McCall, C., Schneider, R., Caton, K., Hundley, C., Hopkins, L., Ensor, K., Domakonda, K., Kalvapalle, P., Persse, D., Williams, S., & Stadler, L. B. (2023). Wastewater surveillance of SARS-CoV-2 and influenza in preK-12 schools shows school, community, and citywide infections. *Water Research*, *231*, 119648. https://doi.org/10.1016/j.watres.2023.119648

Wu, D., Wu, T., Liu, Q., & Yang, Z. (2020). The SARS-CoV-2 outbreak: What we know. *International Journal of Infectious Diseases*, *94*, 44–48. https://doi.org/10.1016/j.ijid.2020.03.004

Zimmerman, K. O., Brookhart, M. A., Kalu, I. C., Boutzoukas, A. E., McGann, K. A., Smith, M. J., Maradiaga Panayotti, G. M., Armstrong, S. C., Weber, D. J., Moorthy, G. S., Benjamin, D. K., Jr, & for The ABC Science Collaborative. (2021). Community SARS-CoV-2 Surge and Within-School Transmission. *Pediatrics*, *148*(4), e2021052686. https://doi.org/10.1542/peds.2021-052686