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Discrepancies in Measured Ethylene Oxide Levels at a Georgia Sampling Site

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B.S.
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2020

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An abstract of
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Abstract

Discrepancies in Measured Ethylene Oxide Levels at a Georgia Sampling Site

By Madelyn Bayles

In 2018, the Environmental Protection Agency released a National Air Toxics Assessment that identified the Atlanta-Sandy Springs-Roswell Metropolitan Statistical Area as one of 18 areas in the United States at possible increased risk from ethylene oxide (EtO) pollution. Exposure to EtO may lead to health risks ranging from bronchitis to various cancers. Amid community concern, the Georgia Environmental Protection Division began an ambient air pollution study with sampling locations in Cobb County, the city of Covington, and Fulton County. Both active samplers, the traditional method of sampling EtO, and passive samplers, a newer method, were used. Samples were then sent to two different laboratories, ERG and EPD, for analysis. Data from the active and passive sensors were compared to each other, as were data from the two labs. Paired t-tests and Pearson correlation analyses were run. For the sensors, it was found that the active (mean (M) = 0.17 μg/m3, standard deviation (SD) = 0.12 μg/m3) and passive sensors (M = 0.25 μg/m3, SD = 0.19 μg/m3) took significantly different measurements ($t(22) = 2.1$, $p = 0.048$), and had a non-statistically significant moderate, positive correlation ($r(21) = 0.34$, $p = 0.11$). Regarding the labs, there was no significant difference between the results of ERG Lab (M = 0.42 μg/m3, SD = 0.35 μg/m3) and EPD Lab (M = 0.36 μg/m3, SD = 0.29 μg/m3; $t(32) = -1.2$, $p = 0.24$), and they had a moderate, positive, and statistically significant correlation ($r(31) = 0.51$, $p = 0.0024$). Additional research into EtO sampling and laboratory techniques, using different locations and sampler models, would be helpful in increasing understanding of EtO monitoring to the benefit of the public health.

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INTRODUCTION

Background

Ethylene oxide, or EtO, is an air toxic that has recently attracted considerable attention within the United States. An organic compound with a chemical formula of C_2H_4O, EtO is a gas at room temperature and a liquid at temperatures below 11°C.[1] In either state, EtO is highly reactive.[2,3] It has a 3 to 100% flammable range in air; likewise, liquid solutions of more than 4% EtO are flammable.[2,3] EtO can be difficult to detect, as both its gaseous and liquid forms are colorless and its faint but sweet odor is undetectable by humans until long after unsafe concentrations have been reached.[2]

EtO has found use in many industries. It is an effective sterilant, particularly for objects like archival materials, beekeeping supplies, cosmetics, such food products as herbs and spices, medical equipment, and musical instruments, all of which are difficult to sterilize using other methods.[4] EtO is also used in the manufacture of various consumer products, including adhesives, detergents, plastics, polyurethane foam, PVC pipe, solvents, and synthetic fibers.[5,6,8] During the production of ethylene glycol, a key component of antifreeze, EtO acts as an intermediate.[5,7,8]

Because it is used so widely, individuals may come into contact with EtO in a variety of contexts. Among the general public, exposure may occur through contact with certain consumer goods.[9] Agriculture, healthcare, and industrial facility workers may be further at risk, depending on the nature of their work.[10] Additionally, EtO-emitting facilities may expose nearby residents to heightened EtO levels.[10]

In humans, the primary exposure pathway for EtO is inhalation.[10] Once exposure via inhalation occurs, a myriad of health issues may result. Possible acute health effects include bronchitis, emphysema, and pulmonary edema.[11] Prolonged exposure may lead to more chronic conditions, such as lymphocytic leukemia, myeloma, non-Hodgkin lymphoma, and, for women, breast cancer.[12,13] Alternative exposure pathways, such as eye contact, skin contact, or ingestion, may result in additional adverse health effects.[3,14]

National Air Toxics Assessment

Before developing a new tool for the dissemination of air toxics information, the Environmental Protection Agency (EPA) released the National Air Toxics Assessment (NATA) roughly every three years.[5,15] EPA collected emissions data from industrial, mobile, and natural sources, and then developed air quality models to determine which air toxics, emitters, and locations warranted additional research.[5] Using data from 2014, 2018's NATA determined that 18 sites in the U.S. were in need of further study, with heightened risks associated with EtO.[5]

NATA had not previously identified many of these 18 locations; they were only pinpointed after EtO was established as a carcinogen and the EPA altered its risk calculations in response.[5] When analyzing the 2014 data, EPA noted that due to its mutagenic effects, children would be at an increased risk from EtO.[16] Without data on EtO specifically, the agency followed guidance for general mutagenic chemicals and raised EtO's aggregate unit risk estimate by 1.6 or 60%.[16]

Georgia Environmental Protection Division

As described in the Georgia Environmental Protection Division's (GA EPD) Ethylene Oxide Monitoring Report, the Atlanta-Sandy Springs-Roswell Metropolitan Statistical Area (MSA) was among the 18 locations listed by NATA.[5] In this MSA, two medical sterilization facilities were identified as emissions sources: Becton-Dickinson in the city of Covington and Sterigenics in Cobb County. After receiving notice, GA EPD used more recent data to model the effects of EtO emissions on local populations. Though GA EPD's models suggested less of an impact than NATA, their findings still received community attention and concern and prompted GA EPD to take additional measures against EtO pollution.

Specifically, GA EPD developed an EPA-approved plan for an ambient air quality study focused on EtO.[5] Locations in both Cobb County and Covington would be monitored, as would the General Coffee, Near Road-285, and South DeKalb sites. These three sites, already in use by GA EPD, were chosen for study control and qualitative purposes. In 2020, sampling began in Fulton County as well, after GA EPD data identified Sterilization Services of Georgia as another EtO-emitting medical sterilization facility.

Thanks to an EPA Community-Scale Air Toxics Ambient Monitoring Grant, GA EPD was able to extend the study's timeframe and scope.[5] Sampling was continued through October of 2021 and the study's focus was expanded to include the evaluation of new ambient air monitoring technologies like passive samplers.

Passive samplers, which do not require a power source, can be installed in a variety of locations with minimal impact, making them convenient for community sampling.[5] However, their use as EtO monitors is still being evaluated. The Entech CS1200E, one passive sampler model, was used across the Cobb County, Covington, and Fulton County community areas impacted by EtO-emitting facilities, as well as at the South DeKalb (background urban) monitoring site. Pressurized samplers, such as the ATEC 2200 and the Xonteck Model 910, are more commonly used for monitoring EtO. The ATEC 2200 was used at South DeKalb, while the Xonteck Model 910 was used at both General Coffee and Near Road-285.

After collection, samples were sent to either the EPD Laboratory or the Eastern Research Group (ERG) Laboratory, an EPA contract laboratory, for analysis.[5] Due to separate methodologies, results differed between the laboratories. EPD Lab, for example, repeatedly cleaned its canisters to prevent EtO from forming, while ERG Lab did not, resulting in some ERG Lab canisters being marked as biased high.

Project Aims

This project's overarching purpose is to examine GA EPD EtO data collected and analyzed under different conditions. Data from the South DeKalb site was used, as it was the only study location monitored with both passive and pressurized samplers.[5] The two specific aims of this thesis are as follows:

Aim 1: Two sampler types were used at the South DeKalb site: the Entech CS1200E (a passive sampler) and the ATEC Model 2200 (a pressurized sampler).[5] Their EtO measurements were compared in order to evaluate the Entech CS1200E's use as an EtO monitor.

Aim 2: Both EPD and ERG Labs analyzed South DeKalb EtO samples.[5] The EtO measurements were examined for discrepancies in results between the two labs.

Project Significance

EtO presents numerous health risks in a variety of settings and is difficult to detect with human senses alone.[2] Improving the currently limited understanding of EtO monitoring and analysis will help to ensure that EtO exposure levels remain in a safe range, ultimately reducing the incidence of EtO-related health effects in humans. The evaluation of passive samplers is of particular importance due to their utility as community samplers.[5] If their effectiveness can be confirmed, they may be implemented widely for long-term monitoring that ultimately will benefit public health.

METHODS

Data Collection

Before GA EPD's study formally began, exploratory EtO sampling was conducted at the South DeKalb site.[5] Though the measurements ultimately could not be used due to calibration difficulties, this monitoring period provided GA EPD with experience in sampling and analyzing EtO.

The South DeKalb sampling schedule was based on sampling in Cobb County (near Sterigenics), Covington (near Becton Dickinson), and, later, Fulton County (near Sterilization Services of Georgia), thereby providing regular control data from an urban site not affected by Sterigenics, Becton Dickinson, or Sterilization Services of Georgia.[5] Once every six days, South DeKalb was sampled with both an active sampler (an ATEC 2200) and a passive sampler (an Entech CS1200E). Additionally, for quality assurance purposes, an additional Entech CS1200E was collocated at South DeKalb once a month to check precision.

After collection, samples were analyzed by either EPD Lab or ERG Lab.[5]

Data Analysis

The data was received in a combined Excel document. Information irrelevant to this project was removed, as were any invalid entries, such as those with no sampler type or lab listed. The data were imported into R 4.3.1. To prepare for testing, the standard paired t-test assumptions were checked. Data points from each sensor and lab were paired by date, outliers were identified using boxplots and removed, and the Shapiro-Wilk test was run in order to check normality. The measurements from both the sensors and the labs were plotted to characterize the data, and summary statistics were calculated. Finally, paired two-tailed t-tests were run to assess whether EtO measurements differed between the two sensors and between the two labs.

Correlations between the data streams were also performed in order to assess the relationship between the measurements made by the active sensors versus those made by the passive sensors. Because the data from the sensors were normally distributed, a Pearson correlation analysis was conducted.

RESULTS

Summary Statistics and Visualization

Due to the data being paired individually for the sensors and the labs, the number of data points varied between the two sets, leaving the sensor set with 23 paired data points and the lab set with 39. Summary statistics for both the sensor and laboratory data indicated potentially meaningful differences between the groups (Tables 1 and 2). The median EtO levels for the active sensors and the passive sensors were 0.13 μg/m^3 and 0.18 μg/m^3, respectively; for ERG Lab and EPD Lab, 0.27 μg/m^3 and 0.22 μg/m^3. Differences were also noted between other summary statistics, such as the standard deviations.

Table 1: EtO Concentration Summary Statistics from Sensors, 2019 - 2021

Statistic	Sampler Type	
	Active (in μg/m^3)	Passive (in μg/m^3)
Minimum	0	0
Maximum	0.56	0.76
Median	0.13	0.18
First quartile	0.085	0.11
Third quartile	0.25	0.35
Interquartile range	0.17	0.24
Median absolute deviation	0.10	0.18
Mean	0.17	0.25

Standard deviation of the mean	0.12	0.19
Standard error of the mean	0.025	0.040
95 percent confidence interval of the mean	0.053	0.084

Table 2: EtO Concentration Summary Statistics from Laboratories, 2019 - 2021

Statistic	Lab	
	EPD (in μg/m^3)	ERG (in μg/m^3)
Minimum	0.050	0.085
Maximum	5.7	3.8
Median	0.34	0.29
First quartile	0.17	0.16
Third quartile	0.83	0.61
Interquartile range	0.25	0.45
Median absolute deviation	0.37	0.25
Mean	0.71	0.54
Standard deviation of the mean	1.1	0.73
Standard error of the mean	0.17	0.12
95 percent confidence interval of the mean	0.35	0.24

The below plots (Figures 1 - 7) aid in better understanding the overall shape of the data. To give the data a more cohesive shape, a mean was calculated whenever there were two or more measurements taken on the same day, such as when a collocated passive sensor was run in tandem with the original passive sensor.

Figure 1: Line Plot of Ethylene Oxide Concentration by Date, as Measured by Active Sensors, 2019 - 2021

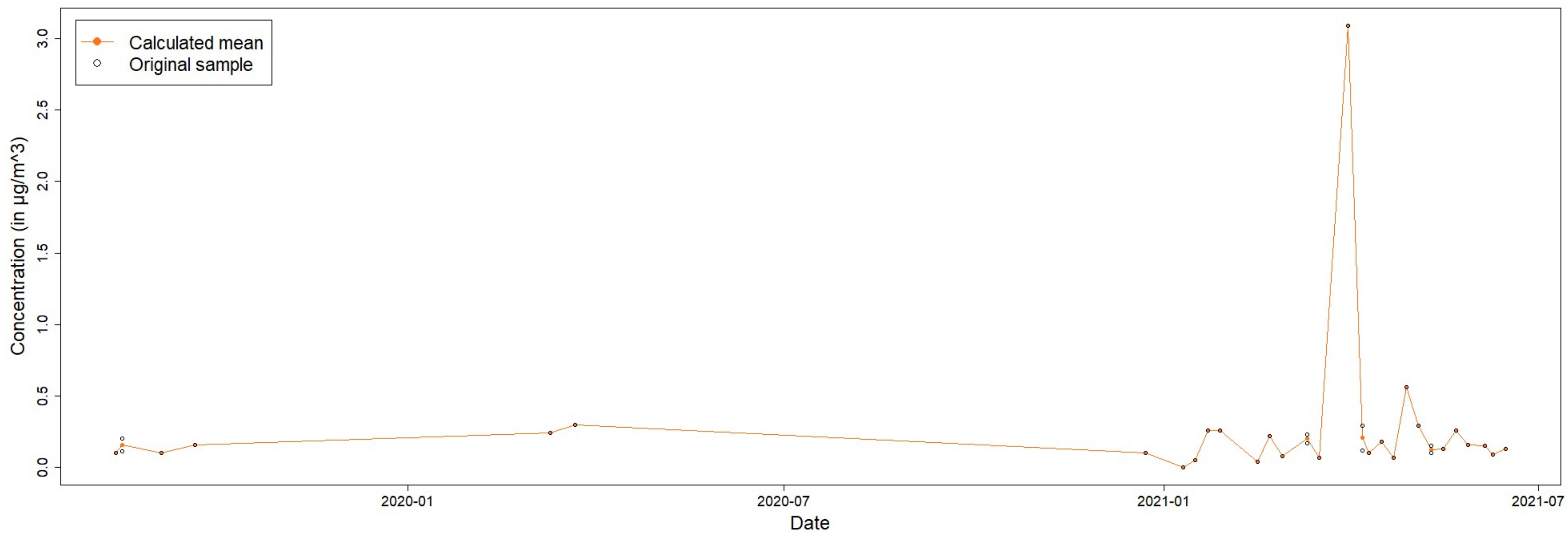


Figure 2: Line Plot of Ethylene Oxide Concentration by Date, as Measured by Passive Sensors, 2019 - 2021

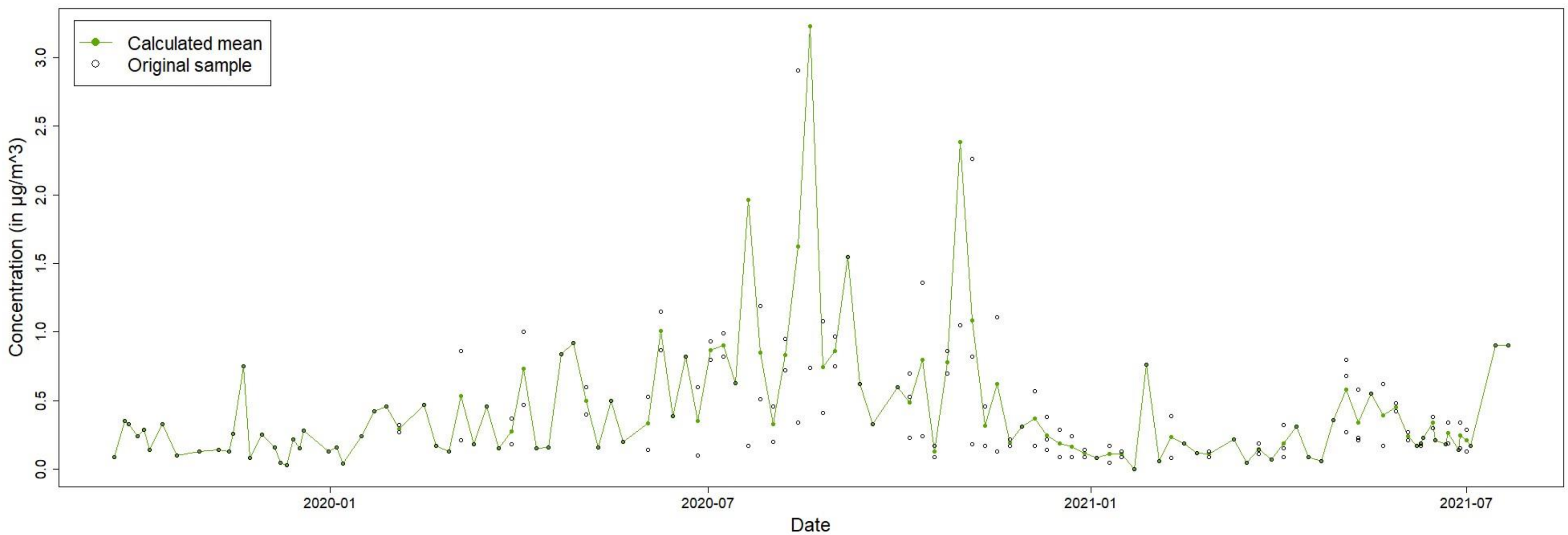


Figure 3: Line Plot of Ethylene Oxide Concentration by Date, as Measured by Active and Passive Sensors, 2019 - 2021

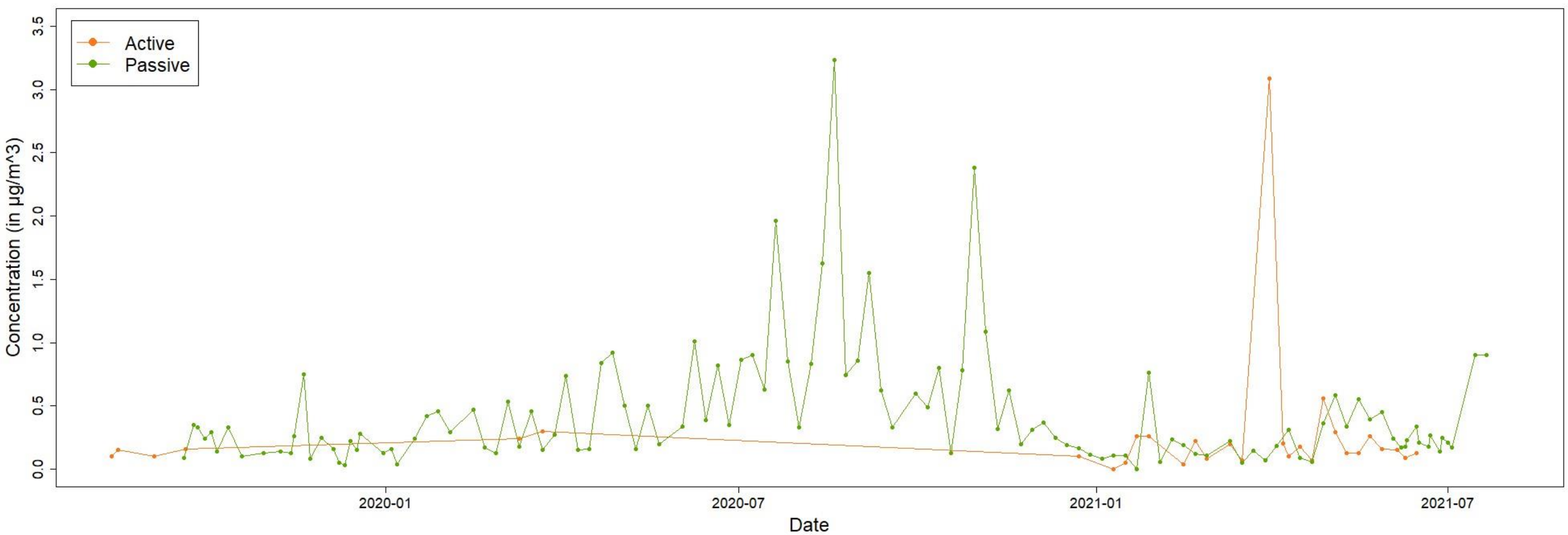


Figure 4: Paired Box Plot of Ethylene Oxide Concentration by Sensor Type, as Measured by Active and Passive Sensors, 2019 - 2021

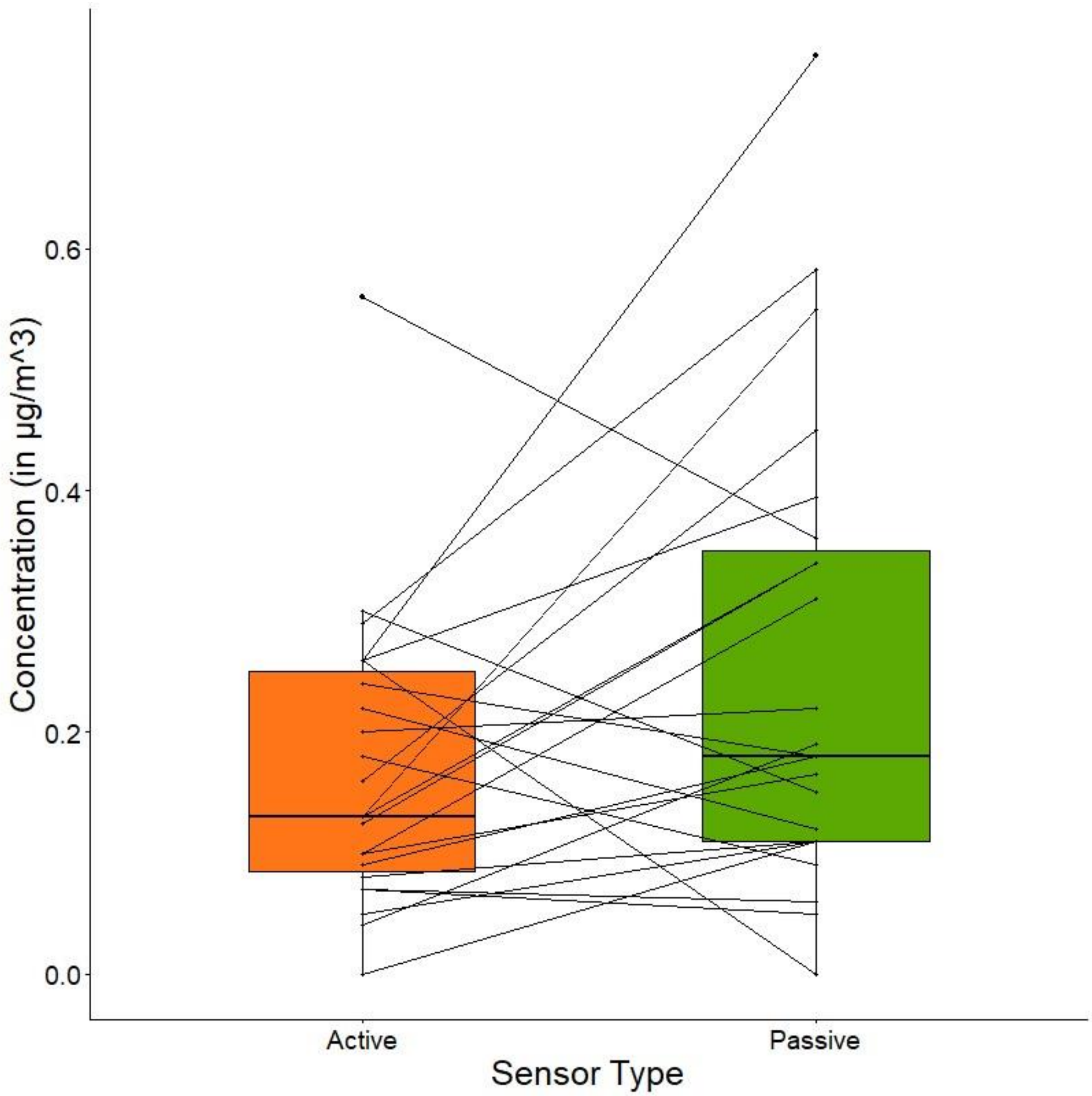


Figure 5: Line Plot of Ethylene Oxide Concentration by Date, as Reported by ERG Lab, 2019 - 2021

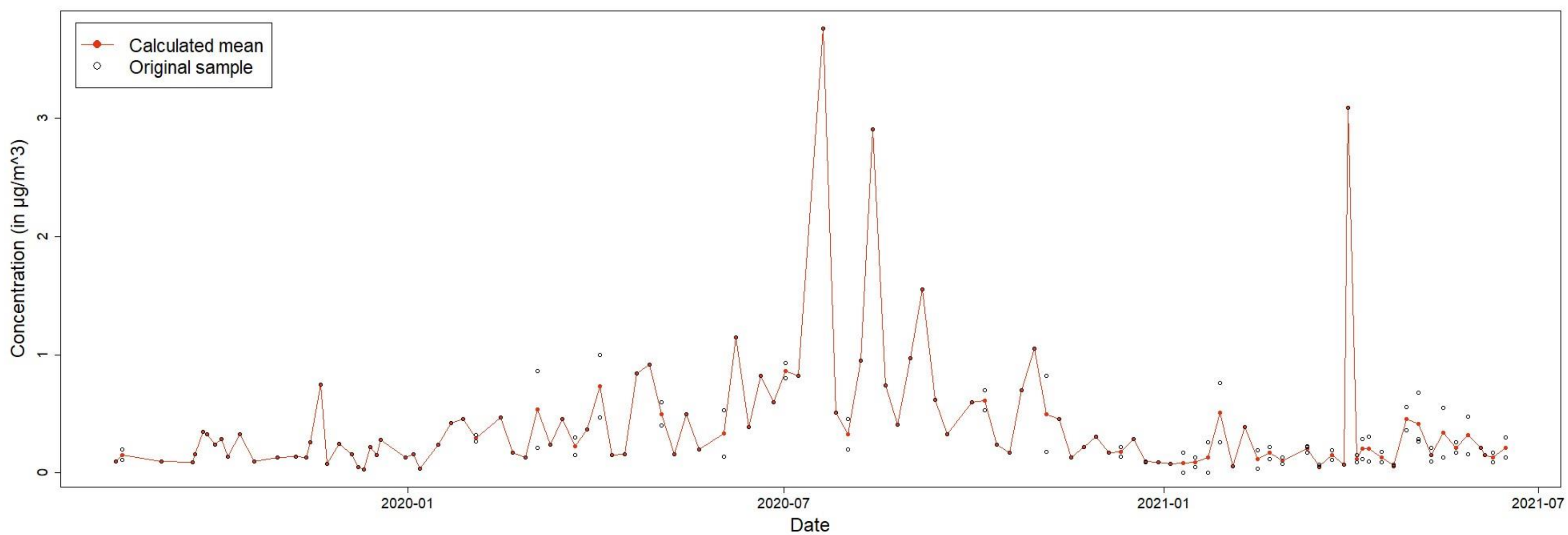


Figure 6: Line Plot of Ethylene Oxide Concentration by Date, as Reported by EPD Lab, 2019 - 2021

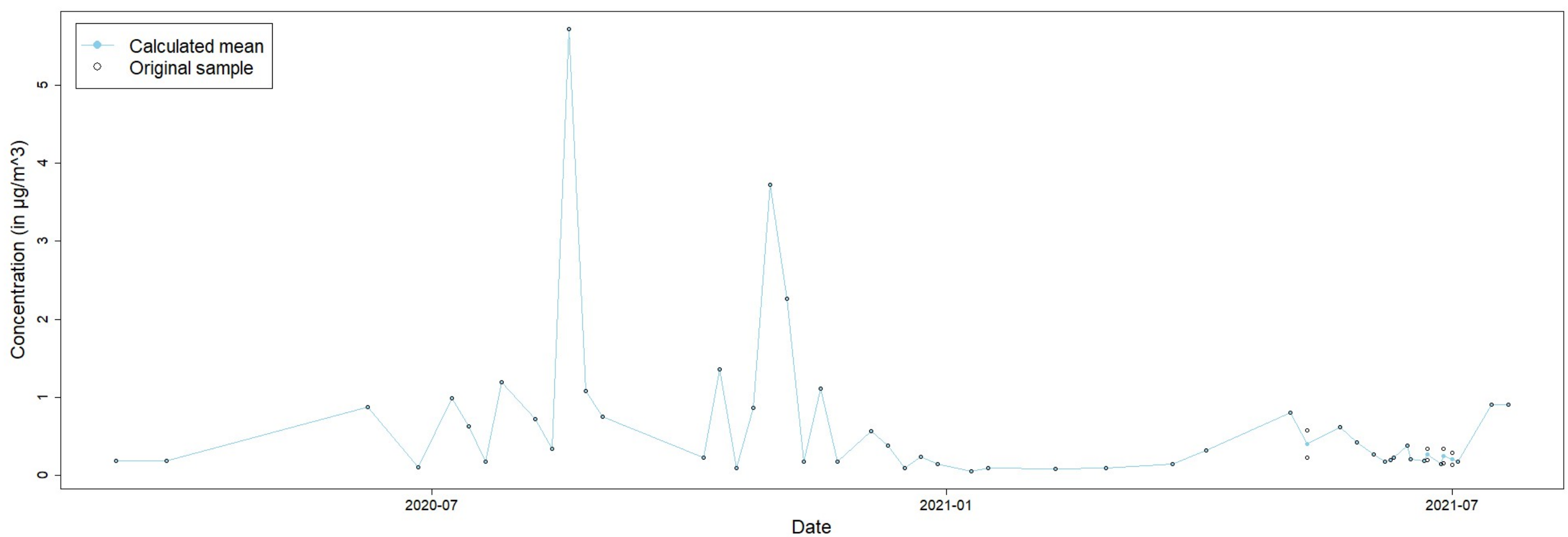
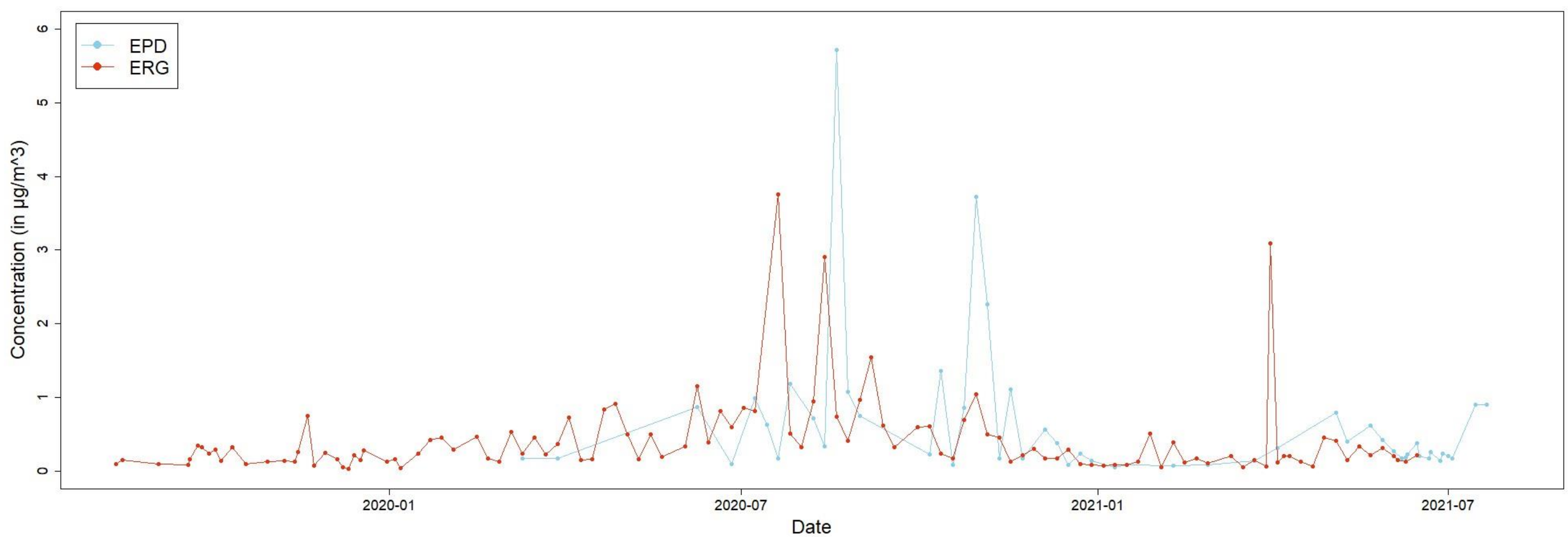


Figure 7: Line Plot of Ethylene Oxide Concentration by Date, as Measured by EPD and ERG Labs, 2019 - 2021



Statistical Tests

Though no outliers were identified among the sensors, several were found among the laboratories and removed. This led to six paired data points being removed from the lab set, leaving 33. An updated table (Table 3) and plot (Figure 8) may be found below. Results from Shapiro-Wilk tests indicated that both the sensor and laboratory data met the normality assumption; the sensors had a p-value of 0.99 and the labs a p-value of 0.18. The quantile-quantile (Q-Q) plots below (Figures 9 and 10) display their normality visually. To demonstrate the importance of removing the outlier data, two alternate, unfiltered plots are presented in Appendix B (Figures 13 and 14).

Table 3: Lab Summary Statistics (Outliers Filtered)

Statistic	Lab	
	EPD (in μg/m^3)	ERG (in μg/m^3)
Minimum	0.050	0.085
Maximum	1.2	1.2
Median	0.27	0.22
First quartile	0.14	0.15
Third quartile	0.72	0.46
Interquartile range	0.58	0.31
Median absolute deviation	0.27	0.19
Mean	0.42	0.36
Standard deviation of the mean	0.35	0.29

Standard error of the mean	0.061	0.050
95 percent confidence interval of the mean	0.13	0.10

Figure 8: Paired Box Plot of Ethylene Oxide Concentration by Laboratory (Outliers Filtered), 2019 - 2021

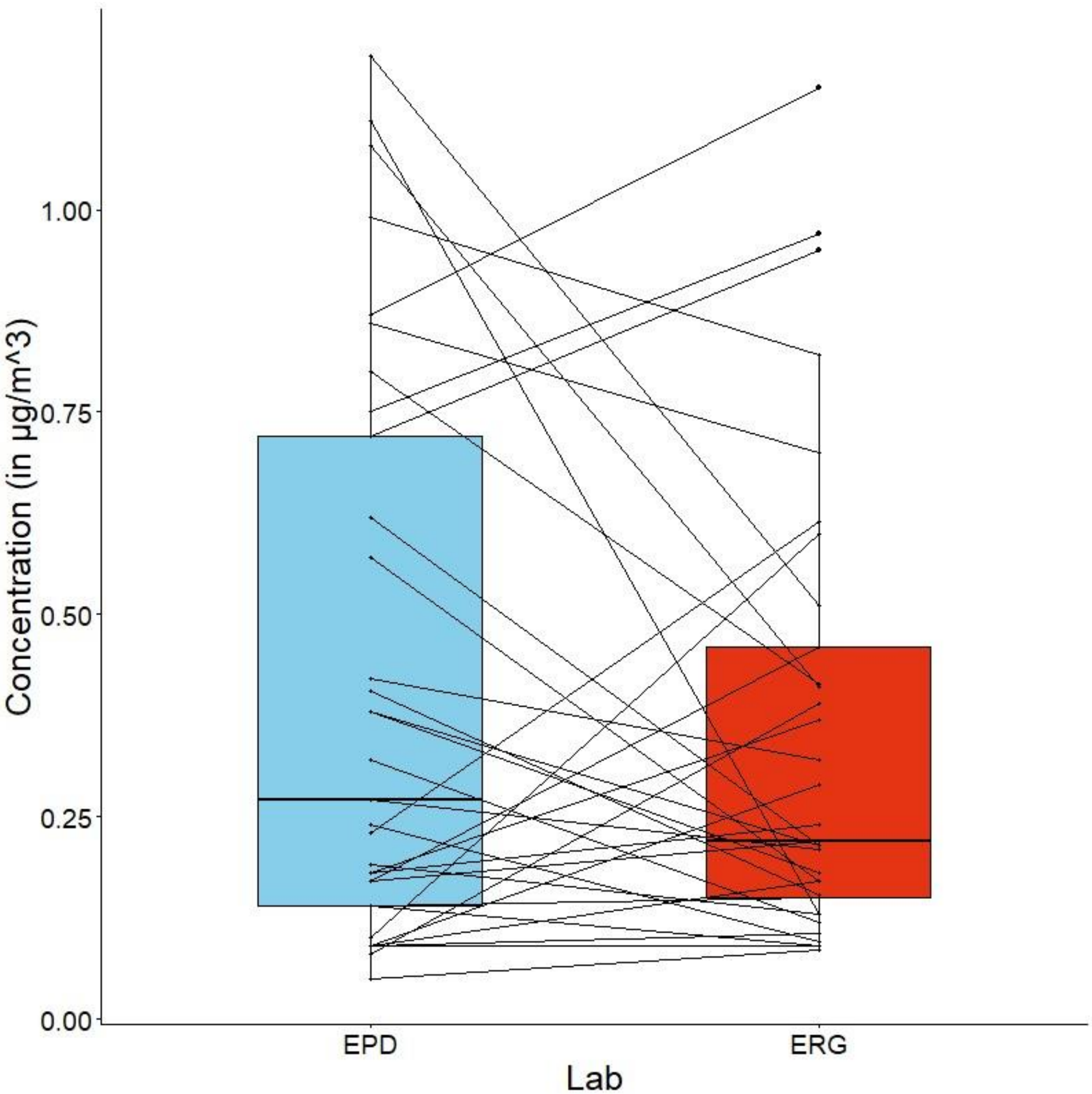


Figure 9: Quantile-Quantile Plot of Sensor Data

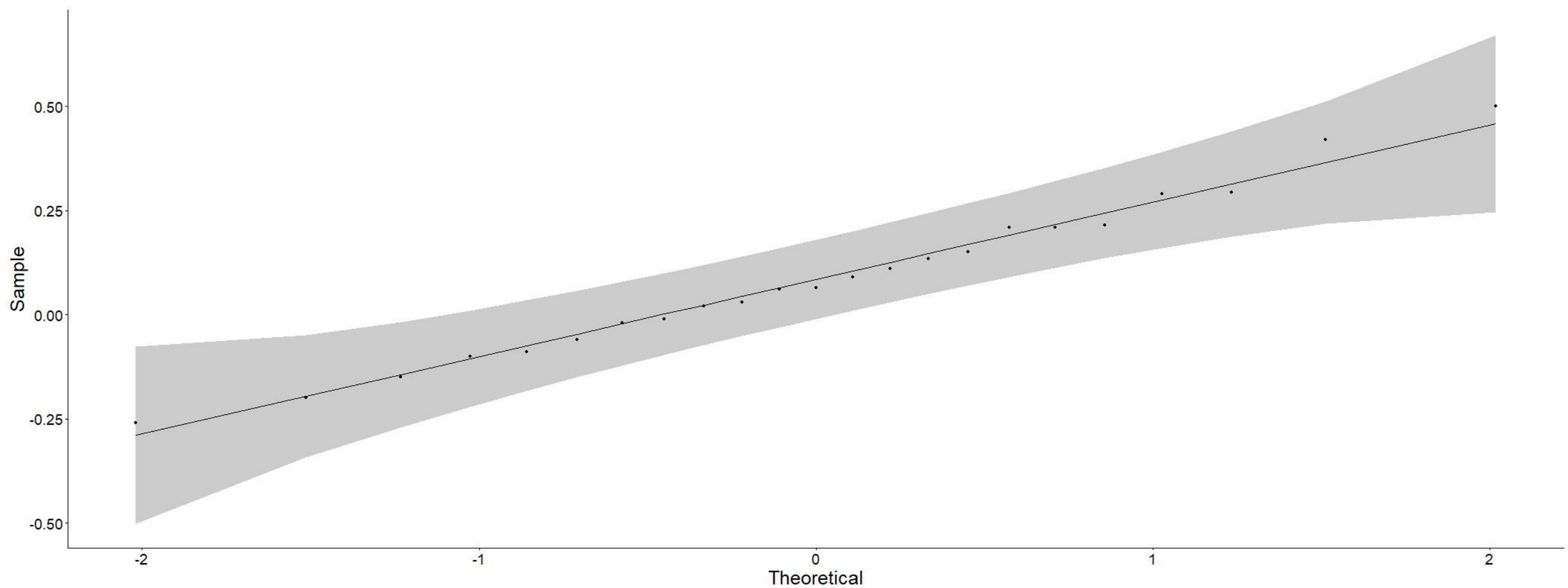
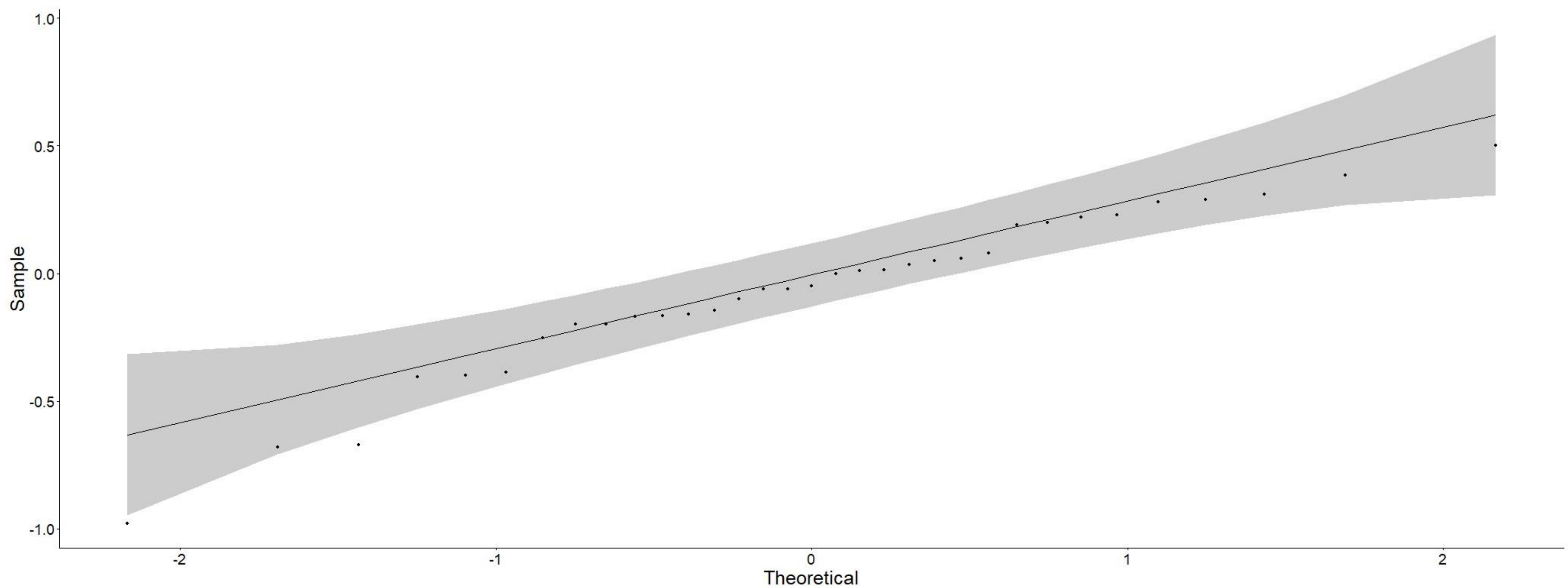


Figure 10: Quantile-Quantile Plot of Laboratory Data (Outliers Filtered)



The final results, shown in Tables 4 and 5, indicated that the active (mean (*M*) = 0.17 μg/m^3, standard deviation (*SD*) = 0.12 μg/m^3) and passive sensors (*M* = 0.25 μg/m^3, *SD* = 0.19 μg/m^3) reported significantly different values ($t(22) = 2.1$, $p = 0.048$). However, no significant difference was found between the measurements reported by ERG Lab (*M* = 0.42 μg/m^3, *SD* = 0.35 μg/m^3) and EPD Lab (*M* = 0.36 μg/m^3, *SD* = 0.29 μg/m^3; $t(32) = -1.2$, $p = 0.24$).

Table 4: Paired T-Test Results for Active vs. Passive Sensors

Component	Result
Test Statistic	2.1
Degrees of Freedom	22
P-Value	0.048

Table 5: Paired T-Test Results for EPD vs. ERG Laboratories

Component	Result
Test Statistic	-1.2
Degrees of Freedom	32
P-Value	0.24

For the sensors, the results of the Pearson correlation analysis (Table 6 and Figure 11) suggested a moderate, positive correlation, that was nonetheless not statistically significant ($r(21) = 0.34$, $p = 0.11$). The results for the laboratories (Table 7 and Figure 12) indicated ($r(31) = 0.51$, $p = 0.0024$) a moderate, positive – but statistically significant – correlation.

Table 6: Pearson Correlation Analysis Results for Active vs. Passive Sensors

Component	Result
Correlation Coefficient	0.34
Degrees of Freedom	21
P-Value	0.11

Table 7: Pearson Correlation Analysis Results for EPD vs. ERG Laboratories

Component	Result
Correlation Coefficient	0.51
Degrees of Freedom	31
P-Value	0.0024

Figure 11: Sensor Scatterplot and Pearson Correlation Analysis Results

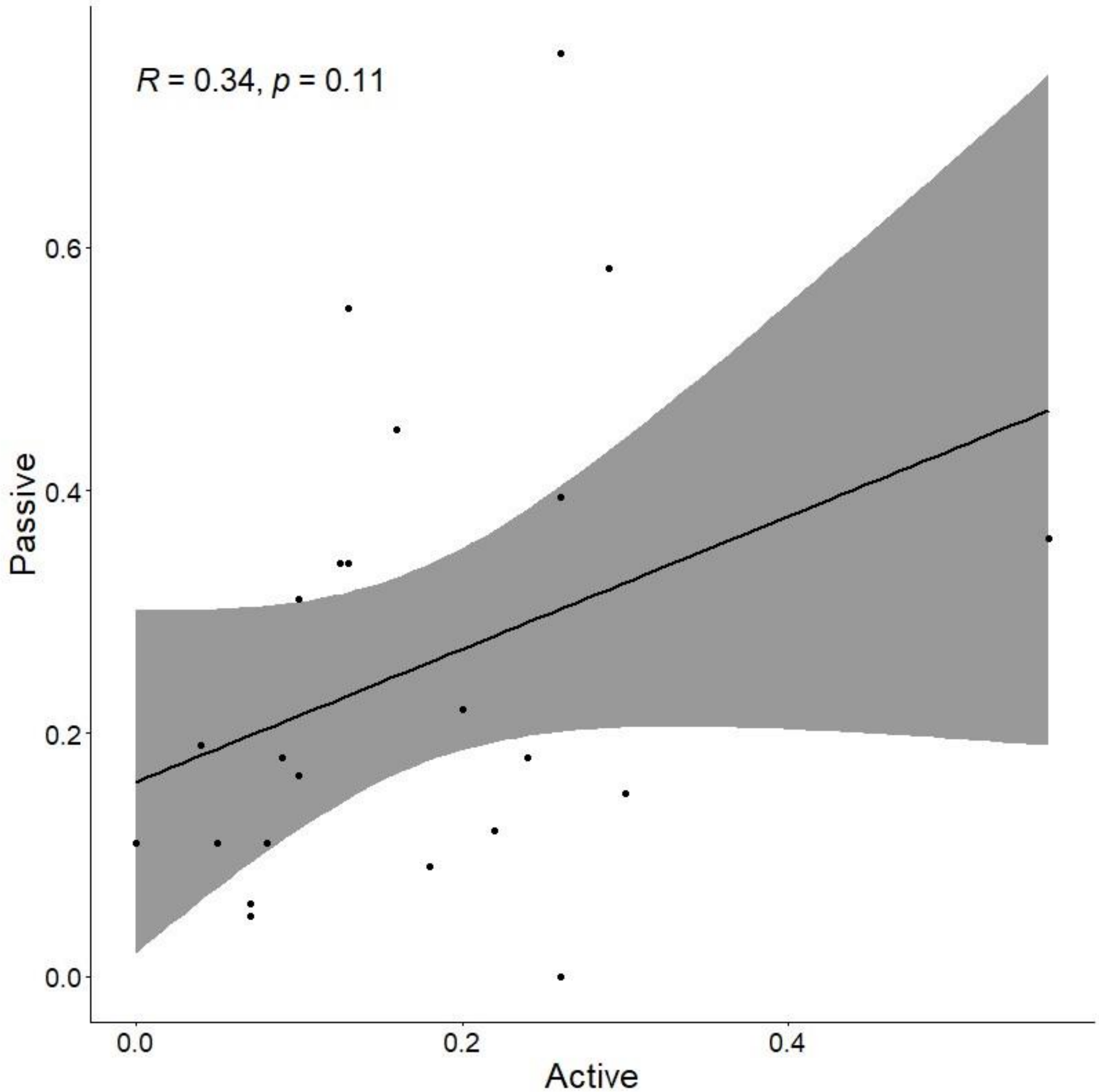
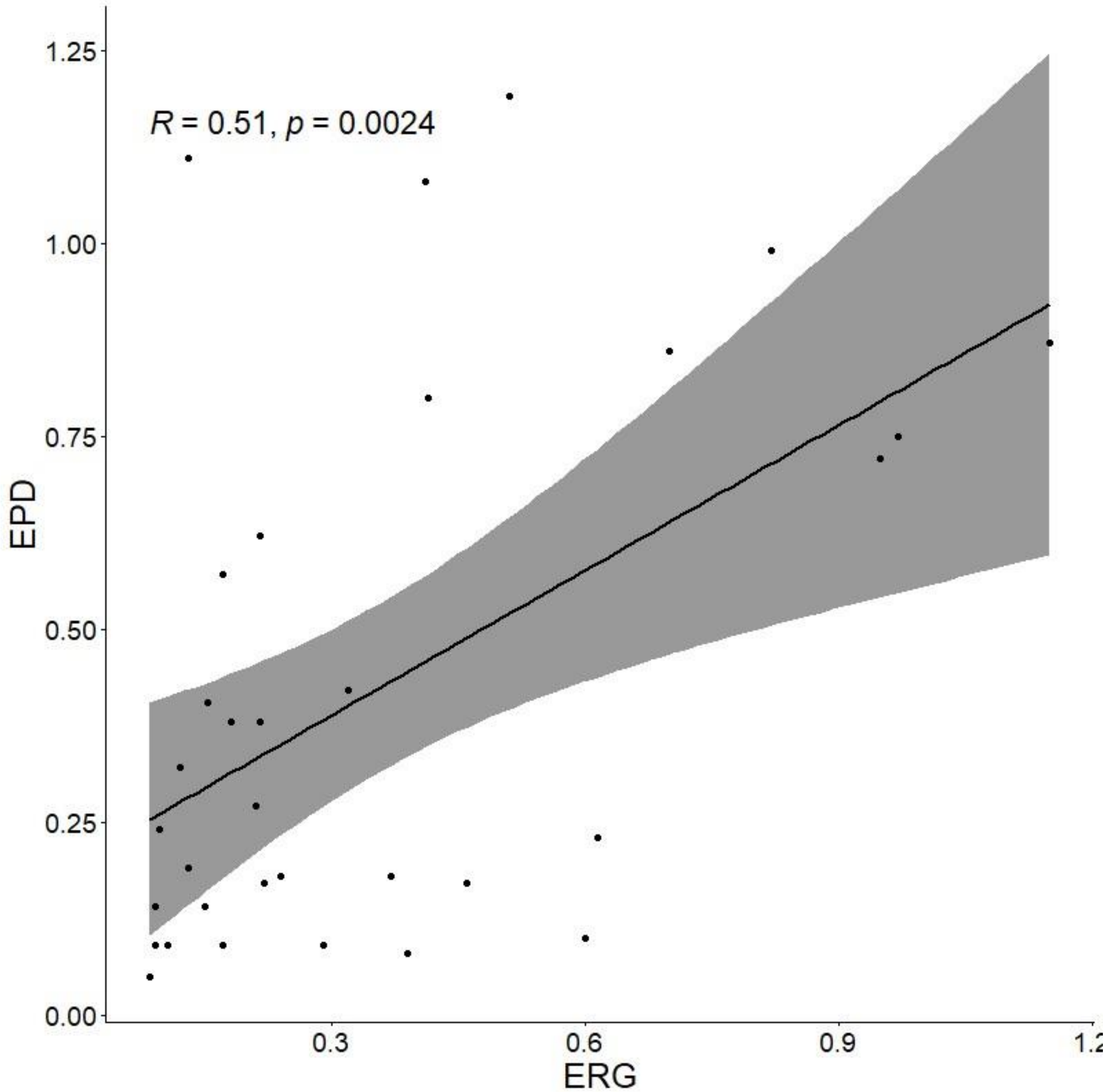


Figure 12: Laboratory Scatterplot and Pearson Correlation Analysis Results



DISCUSSION

Based on the results of the paired t-tests, there was a significant difference between the measurements taken by the active and passive sensors, but not between the analyses of EPD and ERG labs. The Pearson correlation coefficient of the sensors determined no statistically significant correlation, while that of the laboratories found a moderately positive linear correlation. These findings suggest that EtO growth may not be a major concern when analyzing samples, and that active and passive sensors cannot be used interchangeably to measure EtO in communities.

One major limitation to the study was the lack of active sensor data. Before pairing the data, there were only 34 usable active sensor data points, in contrast to the 173 measurements of the passive sensors. This was partly due to the use of a second, collocated passive sensor for quality assurance purposes, and partly due to apparent data entry errors. Additional sample data from an active sensor could have given a fuller, more accurate picture of how the different sensor types compared.

Research on this topic is currently limited, and further investigation is needed. As discussed above, further understanding of EtO sampling tools and techniques could serve to make EtO monitoring both more accessible and effective, which in turn would protect the public health by reducing EtO-related health problems, both immediate and chronic. Future studies could attempt to replicate these findings using different sampling locations or laboratory techniques.

Alternative active and passive sampler models could be used; discrepancies between the sampler results in this study could be due specifically to the ATEC 2200 or the Entech CS1200E. Switching out the ATEC 2200 for the Xonteck Model 910, for example, may produce different results.

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APPENDICES

Appendix A: List of Abbreviations

EPA	Environmental Protection Agency
ERG	Eastern Research Group
EtO	Ethylene oxide (C_2H_4O)
GA EPD	Georgia Environmental Protection Division
MSA	Metropolitan Statistical Area

Appendix B: Additional Plots

Figure 13: Paired Box Plot of Ethylene Oxide Concentration by Laboratory, as Measured by EPD and ERG Labs

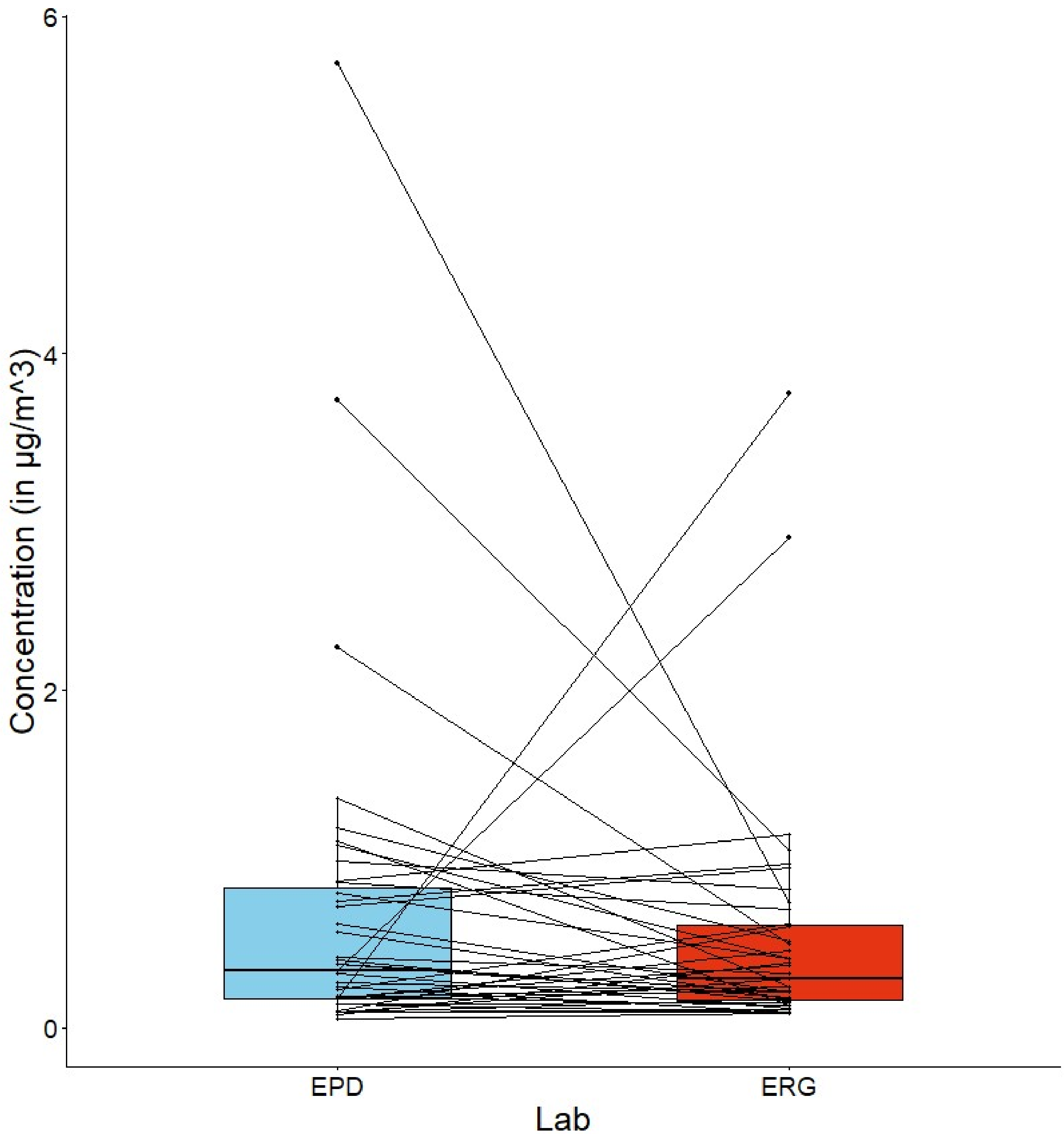

Figure 14: Quantile-Quantile Plot of Sensor Data