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Analyzing Precipitation Acidity Changes Post Train Derailment and Vinyl Chloride Release in East Palestine, Ohio: Exploring Biomedical and Environmental Ramifications

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Abstract

This study investigates the aftermath of a significant train derailment and vinyl chloride release incident in East Palestine, Ohio, with a particular focus on the analysis of precipitation acidity changes and the concentration of vinyl chloride in samples. The research seeks to elucidate the complex relationship between industrial accidents, atmospheric chemistry, and their potential implications for human health and the environment. Through meticulous examination of variations in precipitation acidity patterns, this study provides valuable insights into the dispersion and impact of toxic agents in the environment following industrial mishaps. The results underscore the intricate interplay between these factors, highlighting the need for a multidisciplinary approach that bridges the realms of environmental science and biomedical concerns. This research contributes to a growing body of knowledge that addresses the broader consequences of industrial incidents on public health. It underscores the importance of proactive measures, such as enhanced monitoring and surveillance, risk assessment, public education, and regulatory reform, to mitigate the environmental and health risks associated with industrial activities involving hazardous materials. By fostering collaboration between experts and stakeholders, this study advocates for a holistic approach to safeguarding both our environment and the well-being of communities affected by industrial accidents.

Keywords

pH, Precipitation, East Palestine, ANOVA, Environment, Vinyl Chloride, Health

1. Introduction

Precipitation patterns have a significant impact on the environment, health, infrastructure, and various sectors of society. Understanding the trends and implications of rainfall patterns is crucial for policymakers, environmentalists, and stakeholders to make informed decisions and develop strategies to mitigate the potential risks associated with these changes. This study focuses on analyzing precipitation patterns in Post-Palestine, Ohio and its surrounding states, following a significant environmental incident, using Minitab, a powerful statistical analysis tool.

In recent years, the town of East Palestine, Ohio on February 3rd, 2023, at 8:55 p.m., experienced a devastating train derailment incident involving hazardous chemicals, particularly vinyl chloride gas [1]. Exposure to vinyl chlorine gas has shown an increased incidence of various forms of liver, lung, and brain and leukemia according to the National Institute of Health (NIH). Such an environmental disaster has far-reaching consequences on par with the infamous Chernobyl incident. **Figure 1** demonstrates the East Palestine, Ohio train derailment disaster [2]. The incident, followed by intentional burning of the train cars, resulted in the release of toxic substances into the atmosphere, raising concerns about its environmental impact on the region.

In this study, we focus on the analysis of precipitation patterns in post-Palestine, Ohio, aiming to provide a comprehensive understanding of rainfall trends and their implications. By examining the changes in rainfall patterns, we can assess the potential impact of the incident on the local hydrological cycle and its long-term consequences.

The pH, or hydrogen potential, is a key characteristic that distinguishes between normal and acidic rain. It is a continuous scale ranging from 0 (very acidic) to 14 (basic), with acids having a high concentration of free hydrogen ions. The Litmus pH scale, as depicted in **Figure 2**, illustrates the pH levels of various specimens such as natural rain (pH 6), pure water (pH 5), and seawater (pH 8) [3] [4] [5]. A pH rating of 7 is considered typical for water, indicating a high degree of stability. However, when water approaches a pH characteristic of other acids, it can have a significant environmental impact. This suggests that deviations from the neutral pH of 7 can lead to adverse effects on ecosystems, structures, and natural materials. Monitoring and understanding pH levels in rainwater are crucial for assessing its potential environmental implications and implementing appropriate measures to mitigate any negative consequences.

Figure 1. Aerial photograph of the East Palestine, Ohio Train Derailment.

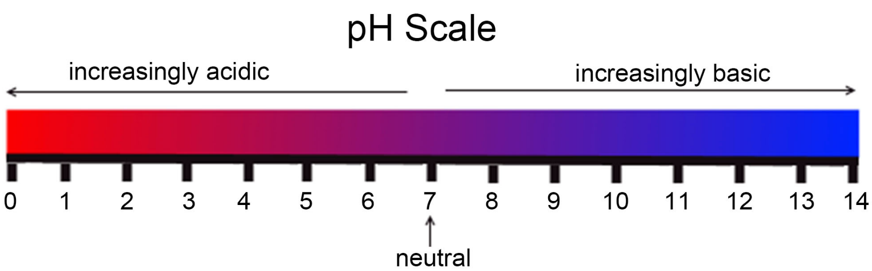


Figure 2. Litmus pH Scale.

Our study utilizes historical precipitation data collected from meteorological stations in the vicinity of Palestine, Ohio. We analyze the temporal and spatial variations in rainfall patterns, including annual precipitation amounts, seasonal distribution, and extreme rainfall events. These analyses will help identify any significant shifts or anomalies in the rainfall regime following the incident.

Furthermore, we explore the implications of these precipitation patterns on various aspects of the local environment and society. This includes assessing the potential effects on groundwater recharge, surface water availability, soil moisture levels, and vegetation dynamics. Additionally, we examine the implications for agricultural practices, water resource management, and potential risks of flooding or drought events [6].

To achieve these objectives, advanced statistical techniques and data analysis methods will be employed [7] [8]. This study aims to provide a comprehensive assessment of the precipitation patterns in post-Palestine, Ohio, and its surroundings, and their implications, contributing valuable insights to the understanding of environmental changes in the region and supporting evidence-based decision-making.

By conducting this comprehensive analysis, we strive to enhance our understanding of the long-term effects of environmental disasters on local precipitation patterns and the subsequent implications for sustainable development and resilience planning. The findings of this study will aid policymakers, environmentalists, and stakeholders in developing effective strategies for mitigating and adapting to the impacts of such incidents in the future.

2. Hypothesis

In this experiment, multiple factors were investigated, including the days since the East Palestine incident, the location of sample collection, and the test method for pH data. It is hypothesized that the time post-Palestine will be a significant factor, with an expected increase in pH over time due to the deposition of chlorine in precipitation. The location of sample collection is also believed to be a significant factor, as distance from the incident site may affect the chlorine content in precipitation. Additionally, the choice of test method is expected to impact the results, with litmus paper being considered a more general pH indicator rather than a precise measurement. In the second block of testing, additional factors such as the brand of mason jar and the number of days of sitting before data collection were introduced as nuisance factors and not hypothesized to have a significant impact.

3. Methodology

To investigate the impact of the train derailment incident in East Palestine, Ohio on precipitation acidity, a systematic experiment was conducted. The experiment considered various factors that could influence pH values, including the number of days since the incident, location of sample collection, method of pH measurement, brand of mason jar, and storage duration of the samples.

Samples of precipitation were collected from different locations in the vicinity of East Palestine, Ohio, and visually inspected for any abnormalities. The sample collection sites were strategically chosen to cover a range of distances from the incident site, allowing for an assessment of spatial variations in pH levels. The samples were collected using standardized protocols to ensure consistency. pH measurements were obtained using different methods, including pH meters and pH indicator strips, to validate the results and account for any measurement variations [9]. The pH measurements were recorded for each sample, and multiple measurements were taken to ensure accuracy.

The collected data were subjected to thorough statistical analysis. Descriptive analysis techniques, such as calculating means, standard deviations, and ranges, were employed to summarize the pH data and identify any trends or patterns. Graphical investigations, including line plots and scatter plots, were used to visualize the pH variations over time and across different locations. To assess the significance of the observed pH variations, an analysis of variance (ANOVA) test was performed. This statistical test allowed for the comparison of pH levels between different factors, such as the number of days since the incident, location of sample collection, and storage duration of the samples. The ANOVA test provided insights into the statistical significance of these factors in influencing precipitation acidity.

4. Sample Collection

This experiment focused on collecting pH samples from precipitation using glass mason jars. The jars were carefully sealed to maintain an airtight environment and prevent contamination. Multiple brands of jars, including Ball, JoyJolt, Kamota, and Kilner, were utilized in the experiment to assess any potential differences in sample collection (**Figure 3(a)** & **Figure 3(b)**).

Each sample was labeled with the collection location and date, allowing for the calculation of the number of days since the Palestine incident. Initially, samples were collected from three locations: Chicopee, Massachusetts (540 miles away), Hamden, Connecticut (489 miles away), and North Haven, Connecticut (491 miles away). In a subsequent phase of the experiment, samples were collected from Greenfield, Massachusetts (574 miles away) and West Haven, Connecticut (479 miles away).

The number of samples collected varied across different locations and dates, reflecting the natural variability in precipitation events during the experimental period. Prior to conducting pH tests, visual inspections of the samples were performed. It was observed that certain samples exhibited black specks or sediment, which may have implications for the analysis and interpretation of pH results [10].

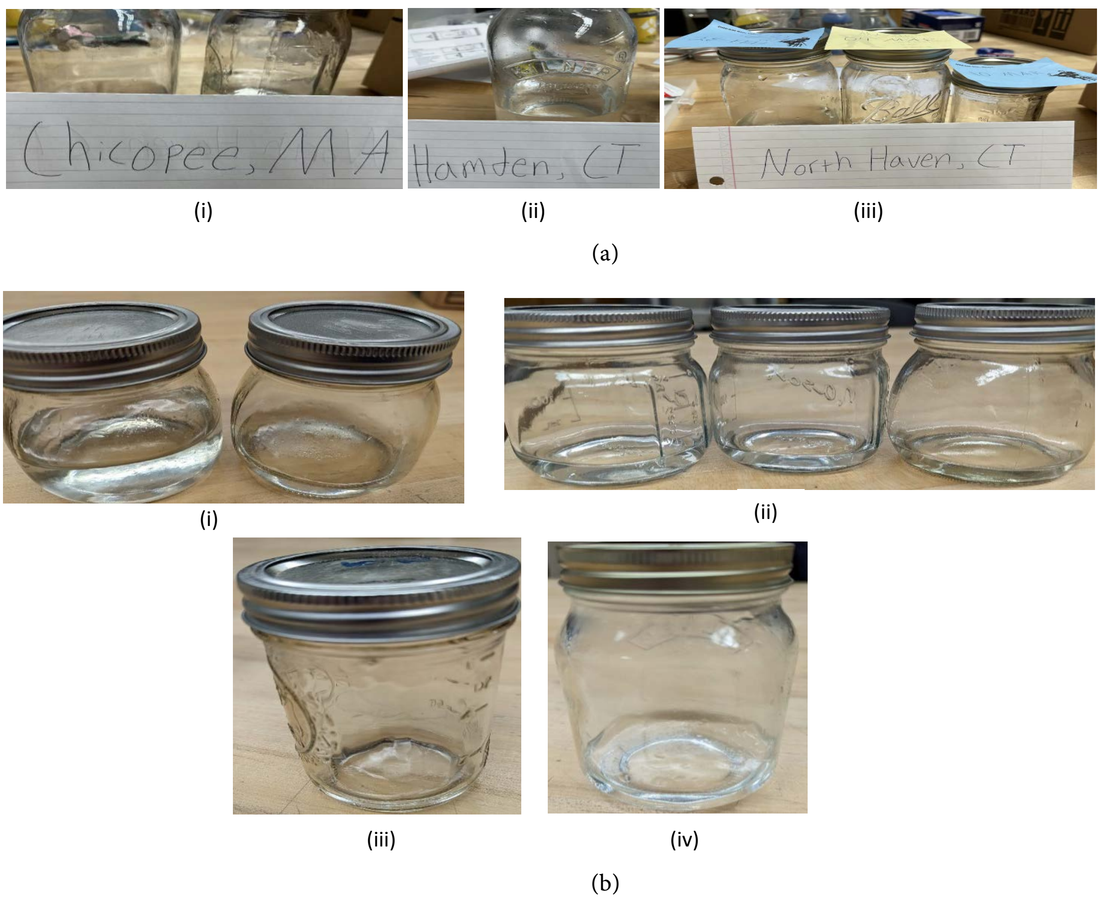


Figure 3. (a) Precipitation samples collected from (i) Chicopee, MA (ii) Hamden, CT, and (iii) North Haven, CT; (b) Precipitation samples collected from (i) West Haven, CT (ii) Hamden, CT, (iii) Greenfield, MA and (iv) North Haven, CT.

The comprehensive sample collection process in this experiment ensures the inclusion of multiple locations and time periods, allowing for a robust analysis of precipitation acidity and its variations. This information is crucial for understanding the long-term consequences of the Palestine incident and its impact on the environment and health.

5. Data Collection

The vinyl chloride concentration in the collected samples was determined through the utilization of Gas Chromatography-Flame Ionization Detection (GC-FID), instrument HP5896 plus II, and software Agilent's Chemstation. This analytical technique measures the presence of organic compounds by detecting the ionization of the sample when exposed to a flame. **Table 1** shows the concentration of vinyl chloride quantified and reported in milligrams per liter (mg/L).

For pH measurements, three different methods were employed: pH meter, litmus paper, and a water test kit. The pH meter utilized a probe with an electrode to measure the voltage generated by ion exchange, providing digital pH values. Litmus paper, treated with a dye, changed color in response to the liquid tested, allowing pH levels to be determined using a color chart. The water test kit consisted of 16 different tests, including pH, impurities, and foreign substances, utilizing test strips and a color chart.

In the initial study, both the pH meter and litmus paper were used for testing each sample, with five replicates for each method. However, in the second study, the litmus paper was replaced with the water test kit due to its limited relevance to the project's objectives. The water test kit provided information on multiple parameters, with a particular emphasis on chlorine. In the second round of testing, each sample was assessed using the pH meter with five replicates, while the 16-in-1 test strip from the water test kit was utilized for one replicate per location.

The utilization of multiple measurement methods ensured comprehensive pH data collection and allowed for cross-validation of results. This approach strengthens the reliability and accuracy of the pH measurements obtained, facilitating a more robust analysis of the impact of the incident on precipitation acidity.

Table 1. Concentration of vinyl chloride (mg/L).

Sample Location	Concentration
North Haven, CT	0.0023
North Haven, CT	0.002
North Haven, CT	0.0022
Hamden, CT	0.0021
Chicopee, MA	0.0028
East Palestine, OH	0.0036
East Palestine, OH	0.0035
Hamden, CT, CT	0.0022
Hamden, CT	0.0021
East Palestine, OH	0.0035

6. Minitab Methodology

In this study, Minitab, a powerful statistical analysis software, was utilized to analyze a tabulated sample data set. Minitab offers a wide range of statistical analysis capabilities and is commonly used across various industries.

Several statistical techniques provided by Minitab were employed in the analysis, including hypothesis testing, ANOVA (analysis of variance), and possibly regression analysis. These techniques allowed for inferences, conclusions, and comparisons to be made based on the sample data

Minitab's functionalities played a crucial role in this study, enabling complex statistical analyses and providing meaningful insights from the data. The software facilitated a deeper understanding of relationships, patterns, and statistical significance, supporting evidence-based decision-making and process improvements.

Overall, Minitab served as a valuable tool, providing the necessary statistical analysis techniques to uncover insights and draw reliable conclusions from the tabulated sample data [10].

7. Initial and Second Blocks of Testing

In the initial block of testing, factors such as location, days post-Palatine incident, and method of testing (pH meter or litmus paper) were considered. Descriptive statistics and graphical representations were used to gain insights into the data. A two-way ANOVA was performed using Minitab to determine significant differences among the groups.

In the second block of testing, additional factors were introduced, including days sitting in a jar, jar brand, and factor's location. The data was organized into two blocks: initial testing and the second round of testing. Descriptive statistics and plots were generated for each factor, and one-way ANOVA tests were conducted.

Model Adequacy Checks and Tukey Multiple Comparison tests were performed to assess the adequacy of the model and evaluate mean differences between factor levels.

These comprehensive statistical analyses facilitated a thorough understanding of the data and helped identify significant differences and relationships among the factors. Minitab's functionalities played a crucial role in conducting these analyses, allowing for reliable conclusions to be drawn from the data.

8. Data

Initial Block of Testing: Experimental Descriptive Statistics

Descriptive statistics were calculated for the samples collected at each location: Chicopee, Hamden, and North Haven. The statistics tables (**Tables 2(a)-(c)**) provide important information about the numerical data, including measures such as the mean, standard deviation, minimum, maximum, and quartiles. These statistics help characterize the distribution of the data, providing insights into its variability and central tendency.

9. Statistics

Table 2. (a) Descriptive statistics for Chicopee location; (b) Descriptive statistics for Hamden location; (c) Descriptive statistics for North Haven location.

(a)

Variable	Days Since Palestine, Ohio	Total Count	Mean	StDev	Minimum	Median	Maximum
pH	26	10	6.458	0.701	5.620	6.510	7.300
	30	10	6.684	0.416	5.940	6.725	7.200

(b)

Variable	Days Since Palestine, Ohio	Total Count	Mean	StDev	Minimum	Median	Maximum
pH	26	10	6.564	0.342	6.040	6.645	7.000

(c)

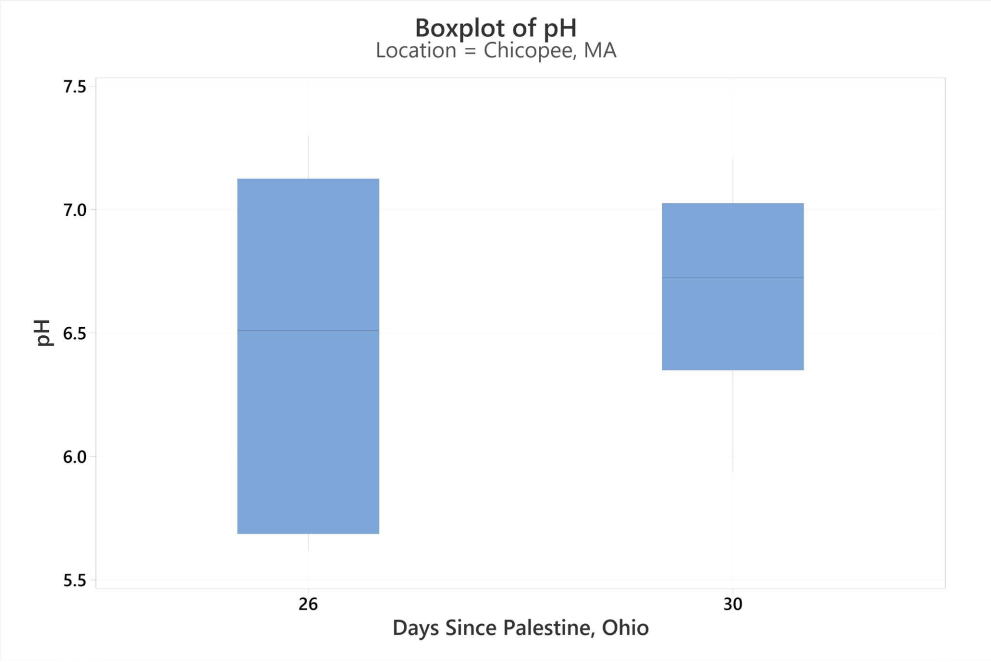
Variable	Days Since Palestine, Ohio	Total Count	Mean	StDev	Minimum	Median	Maximum
pH	26	10	6.290	0.725	5.260	6.465	7.000
	30	10	6.895	0.355	6.350	6.960	7.400
	36	10	6.547	0.348	6.110	6.660	7.000

10. Graphical Investigation

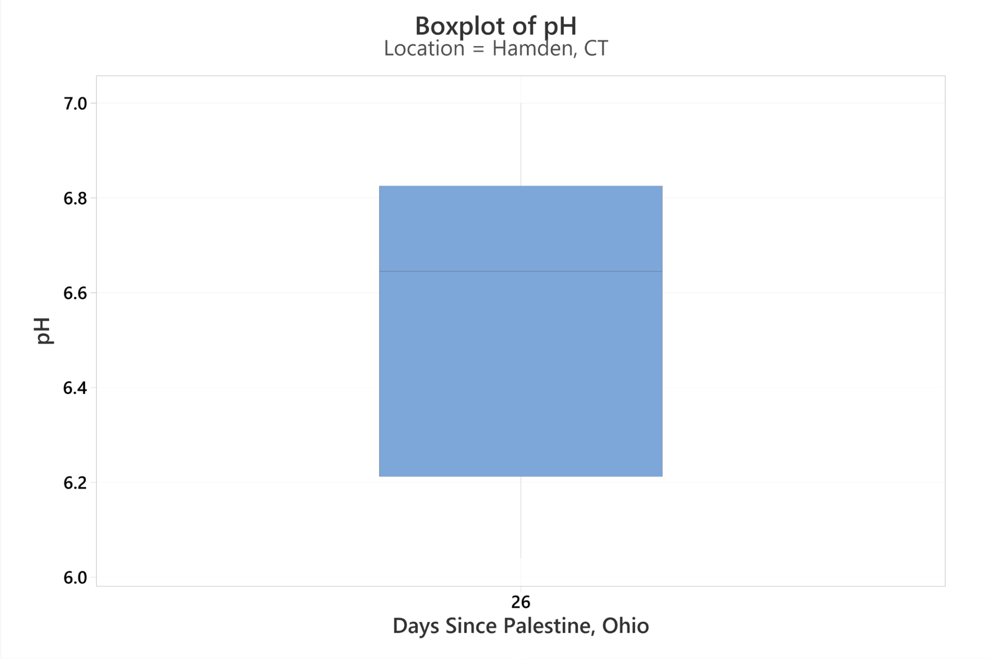
Boxplots, also known as box and whisker plots, offer a concise visual summary of the descriptive statistics of a dataset. They provide information about the distribution, variability, and potential outliers within the data. In this study, boxplots were used to present the pH values for different locations, with each location having its own boxplot. The vertical axis represents the pH value, while the horizontal axis represents the number of days since the Palestine incident. The box in the plot represents the interquartile range, indicating the spread of the middle 50% of the data. The horizontal line inside the box represents the median pH value. The whiskers extend to the minimum and maximum values within a certain range, excluding outliers, which are depicted as individual points beyond the whiskers.

Figures 4(a)-(c) display the boxplot of pH values for different locations, allowing for a visual comparison of the pH levels and their variability across locations and days post-Palestine incident. The spread of values within each boxplot provides insights into the distribution of pH values at each location. Appendix A also includes other comparative plots, such as histograms and individual plots of pH vs. days post-Palestine for each location. These additional plots provide further information about the data distribution and patterns, supporting the analysis and interpretation of the pH data.

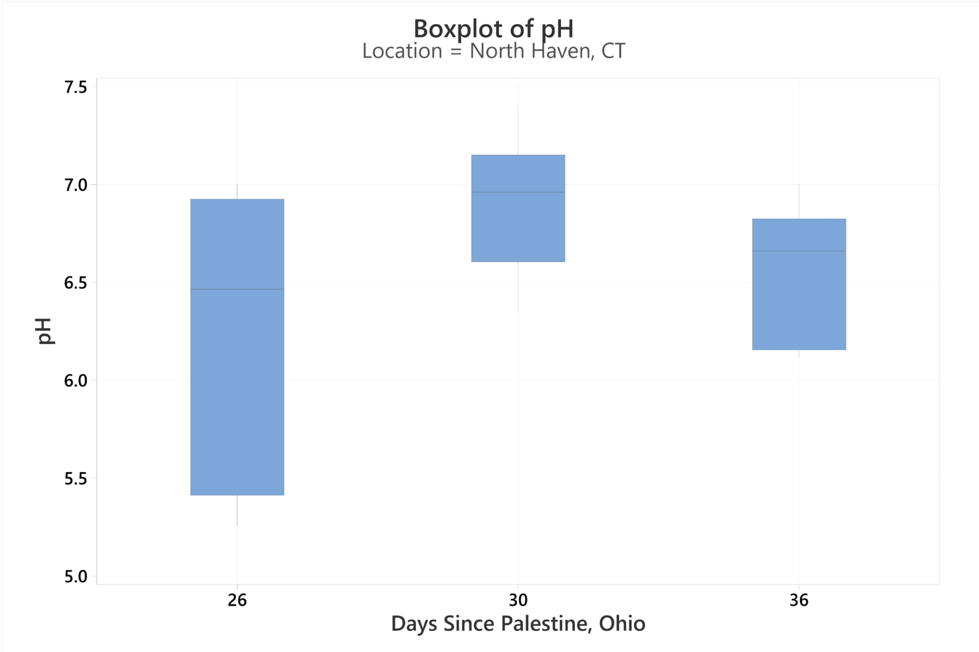
The utilization of boxplots and other comparative plots enhances the understanding of the dataset by providing a graphical representation of the pH values and their relationships with the number of days since the Palestine incident. These visual summaries aid in identifying potential trends, variations, and outliers in the data, which will be further explored and analyzed using statistical methods.



(a)



(b)



(c)

Figure 4. (a) Boxplot of pH vs days since Palestine incident; (b) Boxplot of pH vs days since Palestine incident; (c) Boxplot of pH vs days since Palestine incident.

11. Numerical General Linear Model Output from Minitab

General Linear Model (GLM) analyzed pH levels in water, considering different locations, days since an event in Palestine, Ohio, and two measurement methods (Litmus and Meter). The GLM model explained 74.63% of the pH variation, with an adjusted R-squared of 72.28%, indicating a good fit for the data. The predicted R-squared was 68.88%, suggesting reasonable predictive capabilities. (Table 3(a) & Table 3(b))

The Analysis of Variance (ANOVA) revealed that the days since the event significantly impacted pH levels (F-value = 11.51, p-value < 0.001). The choice of measurement method also had a significant effect on pH (F-value = 135.82, p-value < 0.001). However, the location factor did not show a significant influence on pH (F-value = 1.62, p-value = 0.207), although Hamden, CT, demonstrated a nearly significant effect (p-value = 0.080). (Table 3(c) & Table 3(d))

The coefficients analysis indicated that both 26 days (p-value = 0.001) and 30 days (p-value < 0.001) had a significant impact on pH compared to 36 days. Similarly, the choice of method, Litmus or Meter, significantly influenced pH levels (p-value < 0.001). (Tables 3(e)-(g))

Tables 3(a)-(g) show the Numerical General Linear Model output from Minitab

12. Second Block of Testing

12.1. Experimental Descriptive Statistics

The descriptive statistics play a crucial role in understanding the numerical data before conducting the ANOVA analysis. In this study, the descriptive statistics were organized based on different factors, including location, days since the Palestine, Ohio incident, days sitting in the jar, and jar brands. These factors are essential in examining the variation and characteristics of the data.

Table 4(a) presents the descriptive statistics for the location factor, providing information on the central tendency, variability, and distribution of the data for each location. The statistics include measures such as the mean, standard deviation, minimum, maximum, and quartiles, which help in understanding the spread and range of the data for different locations.

Table 4(b) displays the descriptive statistics for days since the Palestine, Ohio incident. This table provides insights into how the pH values vary over time since the incident. The statistics help identify any patterns or trends that may exist in the data and provide a better understanding of the changes in pH levels as time progresses.

Table 3. (a) General linear model; (b) Factor information; (c) Analysis of variance; (d) Model summary; (e) Coefficients; (f) Regression equation; (g) Fits and Diagnostics for unusual observations.

(a)

Method	
Factor coding	(−1, 0, +1)

(b)

Factor	**Type**	**Levels**	**Values**
Location	Fixed	3	Chicopee, MA, Hamden, CT, North Haven, CT
Days Since Palestine, Ohio	Fixed	3	26, 30, 36
Method	Fixed	2	Litmus, Meter

(c)

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**p-Value**
Location	2	0.2453	0.1226	1.62	0.207
Days Since Palestine, Ohio	2	1.7402	0.8701	11.51	0.000
Method	1	10.2672	10.2672	135.82	0.000
Error	54	4.0822	0.0756		
Lack-of-Fit	6	1.8824	0.3137	6.85	0.000
Pure Error	48	2.1998	0.0458		
Total	59	16.0911			

(d)

S	**R-sq**	**R-sq (adj)**	**R-sq (pred)**
0.274948	74.63%	72.28%	68.88%

(e)

Term	Coef	SE Coef	T-Value	p-Value	VIF
Constant	6.6299	0.0481	137.95	0.000	
Location					
Chicopee, MA	−0.0741	0.0561	−1.32	0.192	2.01
Hamden, CT	0.1267	0.0710	1.78	0.080	2.22
North Haven, CT	−0.0526	0.0561	−0.94	0.353	*
Days Since Palestine, Ohio					
26	−0.1926	0.0561	−3.43	0.001	1.39
30	0.2229	0.0561	3.97	0.000	1.18
36	−0.0303	0.0710	−0.43	0.671	*
Method					
Litmus	0.4137	0.0355	11.65	0.000	1.00
Meter	−0.4137	0.0355	−11.65	0.000	*

(f)

pH = 6.6299 − 0.0741 Location_Chicopee, MA + 0.1267 Location_Hamden, CT − 0.0526 Location_North Haven, CT − 0.1926 Days Since Palestine, Ohio_26 + 0.2229 Days Since Palestine, Ohio_30 − 0.0303 Days Since Palestine, Ohio_36 + 0.4137 Method_Litmus − 0.4137 Method_Meter

(g)

Obs	pH	Fit	Resid	Std Resid	
8	5.2600	5.9711	−0.7111	−2.71	R
9	5.4300	5.9711	−0.5411	−2.06	R
10	5.3600	5.9711	−0.6111	−2.33	R
17	6.9200	6.3866	0.5334	2.04	R

R Large residual.

Table 4(c) presents the descriptive statistics for days sitting in the jar, offering insights into the effect of storage duration on the pH values. By examining the mean, standard deviation, and other measures, one can assess whether the storage duration has an impact on the acidity of the precipitation samples.

Table 4(d) provides the descriptive statistics for jar brands, allowing for a comparison of the pH values across different brands of mason jars. The statistics in this table assist in identifying any variations in the pH levels associated with different jar brands, contributing to an understanding of potential factors that may influence the acidity of the samples.

Overall, the descriptive statistics tables provide a comprehensive summary of the key statistical measures for each factor, facilitating a deeper understanding of the data characteristics and variability. These statistics serve as a foundation for the subsequent ANOVA analysis and contribute to the overall interpretation of the study's findings.

Table 4. (a) Descriptive statistics for location; (b) Descriptive statistics for days since Palestine, Ohio; (c) Descriptive statistics for days sitting in a Jar; (d) Descriptive statistics for Jar Brand.

(a)

Variable	Location	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
pH	Chicopee, MA	6.072	0.110	0.349	5.620	5.688	6.055	6.412	6.550
	Greenfield, MA	7.4780	0.0630	0.1410	7.3100	7.3500	7.4800	7.6050	7.6800
	Hamden, CT	7.197	0.124	0.553	6.040	6.797	7.460	7.553	7.590
	North Haven, CT	6.621	0.201	0.901	5.260	6.122	6.380	7.693	7.990
	West Haven, CT	6.3370	0.0246	0.0778	6.2500	6.2675	6.3150	6.4175	6.4400

(b)

Variable	Days Since Palestine, Ohio	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
pH	25	5.921	0.103	0.400	5.260	5.620	6.040	6.130	6.590
	28	7.4780	0.0630	0.1410	7.3100	7.3500	7.4800	7.6050	7.6800
	29	6.4690	0.0853	0.2697	5.9400	6.3275	6.4600	6.6775	6.9200
	35	6.2540	0.0940	0.2102	6.1100	6.1250	6.1600	6.4300	6.6200
	36	6.2700	0.00837	0.0187	6.2500	6.2550	6.2700	6.2850	6.3000
	37	6.4040	0.0201	0.0451	6.3300	6.3650	6.4100	6.4400	6.4400
	38	7.4680	0.0124	0.0277	7.4300	7.4450	7.4600	7.4950	7.5000
	39	7.4500	0.0122	0.0274	7.4200	7.4250	7.4500	7.4750	7.4900
	57	7.7730	0.0631	0.1996	7.5700	7.5875	7.7700	7.9600	7.9900

(c)

Variable	Days Sitting in a jar	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
pH	3.00	6.2540	0.0940	0.2102	6.1100	6.1250	6.1600	6.4300	6.6200
	9.00	6.4690	0.0853	0.2697	5.9400	6.3275	6.4600	6.6775	6.9200
	13.00	5.921	0.103	0.400	5.260	5.620	6.040	6.130	6.590
	14.00	7.7730	0.0631	0.1996	7.5700	7.5875	7.7700	7.9600	7.9900
	32.00	7.4500	0.0122	0.0274	7.4200	7.4250	7.4500	7.4750	7.4900
	33.00	7.4680	0.0124	0.0277	7.4300	7.4450	7.4600	7.4950	7.5000
	34.00	6.4040	0.0201	0.0451	6.3300	6.3650	6.4100	6.4400	6.4400
	35.00	6.2700	0.00837	0.0187	6.2500	6.2550	6.2700	6.2850	6.3000
	43.00	7.4780	0.0630	0.1410	7.3100	7.3500	7.4800	7.6050	7.6800

(d)

Variable	Jar Brand	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
pH	Ball	6.438	0.146	0.799	5.260	5.978	6.250	6.677	7.990
	JoyJolt	7.5840	0.00400	0.00894	7.5700	7.5750	7.5900	7.5900	7.5900
	Kamota	6.898	0.129	0.578	6.250	6.307	6.930	7.460	7.500
	Kilner	6.883	0.207	0.655	6.040	6.213	6.950	7.493	7.680

12.2. Graphical Investigation

The box plots presented in visual representations of the pH levels based on different factors, providing insights into the variability and differences among the categories within each factor.

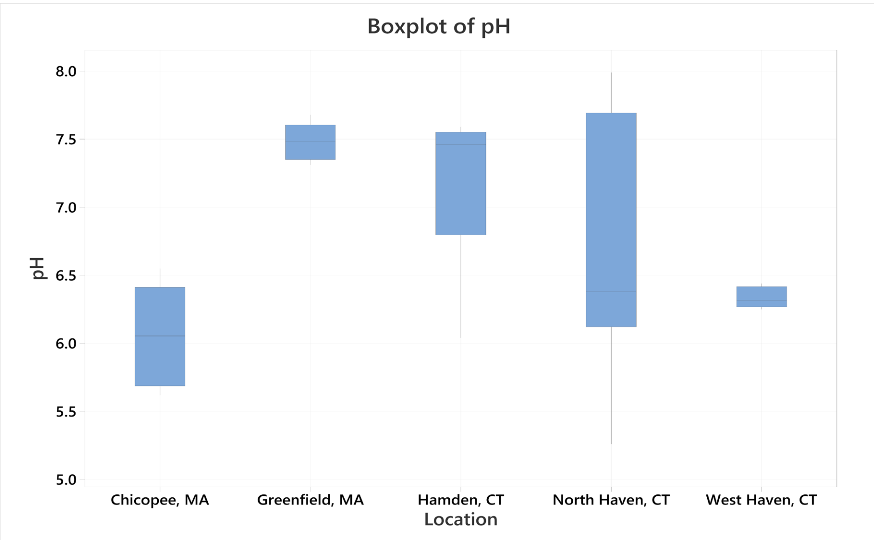
Figure 5(a) displays the box plot of pH levels categorized by location, allowing for a comparison of the precipitation acidity across different collection sites. The box plot visually represents the quartiles, median, and outliers for each location, providing an overview of the distribution and range of pH values at each site.

Figure 5(b) showcases the box plot of pH levels based on the number of days since the Palestine, Ohio incident. This plot allows for an examination of the changes in precipitation acidity over time. By observing the box plots, one can assess any trends or patterns in the pH levels as the days progress since the incident.

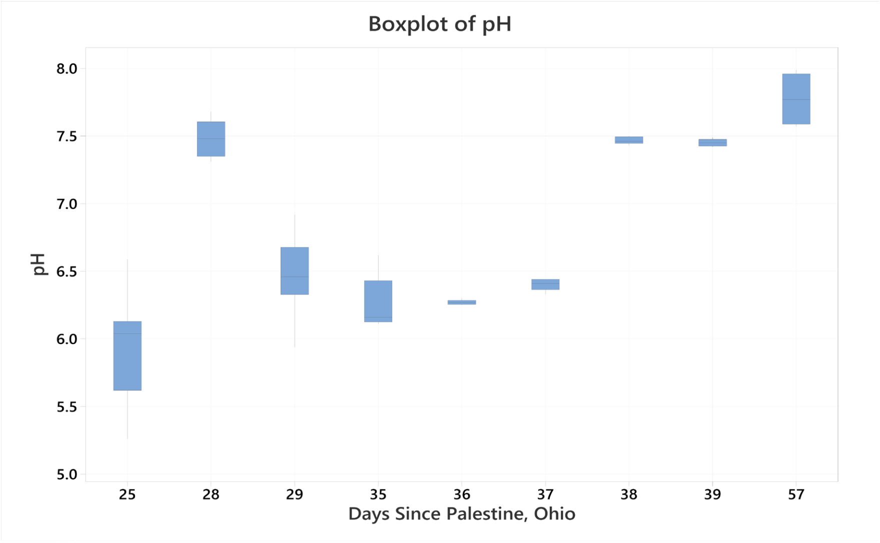
In Figure 5(c), the box plot represents the pH levels related to the duration of time the samples sat in the jar. This plot provides insights into how the storage duration may influence the acidity of the precipitation samples. The spread of values within each box plot indicates the variability in pH levels for different storage durations.

Figure 5(d) presents the box plot of pH levels categorized by jar brand. This plot enables a comparison of the precipitation acidity among different brands of mason jars. By examining the box plots, one can assess whether there are any notable differences in the pH levels associated with each jar brand.

These box plots offer a visual summary of the data, highlighting the differences and variations among the factors being analyzed. They provide a quick and intuitive way to compare the pH levels and identify any potential relationships or patterns. For further visual representations and comparative information, such as histograms and individual plots for each factor, please refer to Appendix A, which offers additional insights into the data distribution and patterns.



(a)



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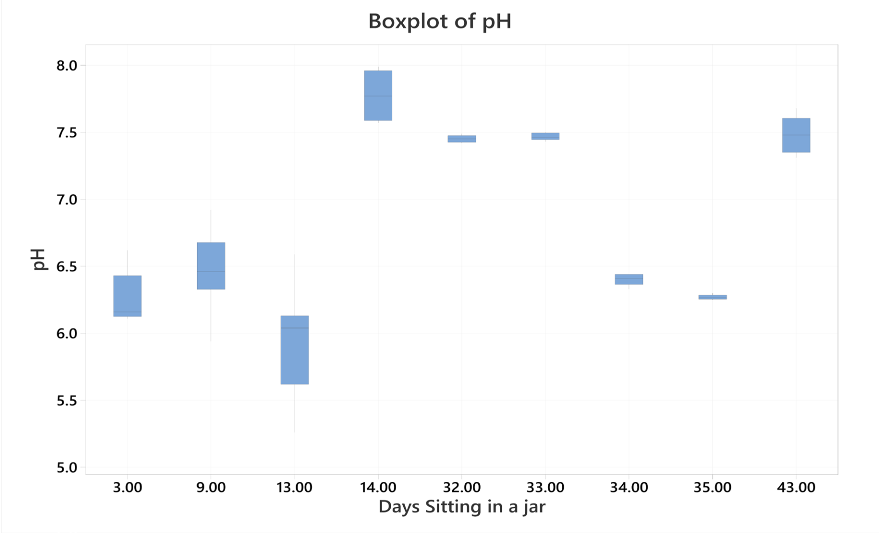
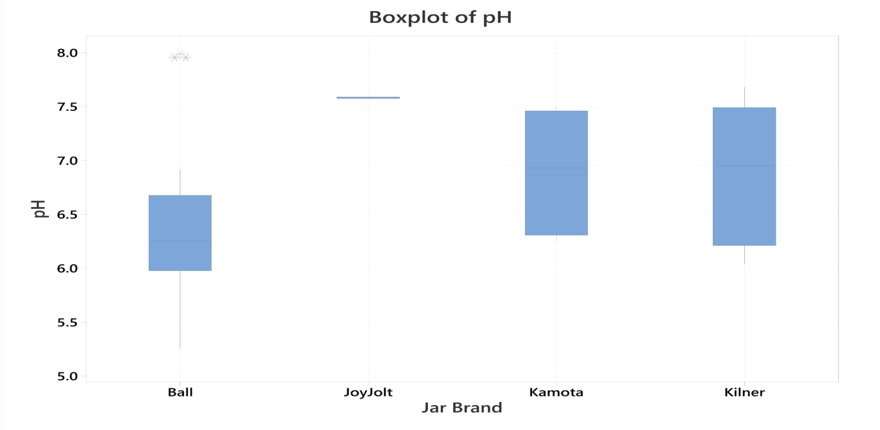


(c)



(d)

Figure 5. (a) Boxplot of pH by location; (b) Boxplot of pH by days since Palestine, Ohio; (c) Boxplot of pH by days siting in the jar; (d) Boxplot of pH by Jar Brand.

12.3. One-Way ANOVA

This study examined the pH of water in the presence of vinyl chloride, focusing on four key factors: Location, Days Since Palestine, Ohio, Days Sitting in a Jar, and Jar Brand. Utilizing one-way ANOVA in Minitab, we obtained valuable insights into how these factors influence water pH (**Table 5(a)**). The geographical location of water sampling sites had a significant impact on pH levels (F-value = 8.87, $p < 0.001$). Our model explained 37.15% of the pH variation, indicating that different locations play a crucial role in determining pH differences (**Table 5(b)**). The time elapsed since the specific event in Palestine, Ohio, showed a highly significant effect on pH (F-value = 63.86, $p < 0.001$). Remarkably, our model demonstrated exceptional explanatory power, accounting for 90.12% of the pH variation, revealing a robust association between time and water pH changes (**Table 5(c)**). The duration of water samples in jars significantly influenced pH (F-value = 63.86, $p < 0.001$). Our model effectively captured 90.12% of the pH variation, emphasizing the criticality of considering the time samples spend in jars when studying pH (**Table 5(c)**). The type of jar used for sample storage had a significant effect on pH (F-value = 4.95, $p = 0.004$). The model accounted for 19.58% of the pH variation, suggesting that the choice of jar can impact water pH (**Table 5(d)**).

12.4. Minitab Output Data

Table 5. (a) Numerical One-way Anova output from Minitab-pH vs. location; (b) Numerical One-way ANOVA output from Minitab-pH vs days since palestine, Ohio; (c) Numerical One-way ANOVA output from Minitab-days sitting in Jar; (d) Numerical One-way ANOVA output from Minitab-pH vs. Jar Brand

(a)

Source	DF	AdjSS	AdjMS	FValue	pValue
Location	4	13.28	3.3189	8.87	0.000
Error	60	22.46	0.3743		
Total	64	35.73			

Model Summary

S	R-sq	Rsq (adj)	Rsq (pred)
0.611761	37.15%	32.96%	29.86%

(b)

Analysis of Variance

Source	DF	AdjSS	AdjMS	F Value	P Value
Days Since Palestine, Ohio	8	32.201	4.02516	63.86	0.000
Error	56	3.529	0.06303		
Total	64	35.731			

Model Summary

S	R-sq	Rsq (adj)	Rsq (pred)
0.251050	90.12%	88.71%	88.10%

(c)

Analysis of Variance

Source	DF	AdjSS	AdjMS	F Value	P Value
Days Sitting in a jar	8	32.201	4.02516	63.86	0.000
Error	56	3.529	0.06303		
Total	64	35.731			

Model Summary

S	R-sq	Rsq (adj)	Rsq (pred)
0.251050	90.12%	88.71%	88.10%

(d)

One-way ANOVA: pH versus Jar Brand

Analysis of Variance

Source	DF	AdjSS	AdjMS	F Value	P Value
Jar Brand	3	6.995	2.3315	4.95	0.004
Error	61	28.736	0.4711		
Total	64	35.731			

Model Summary

S	R-sq	Rsq (adj)	Rsq (pred)
0.686355	19.58%	15.62%	11.48%

13. Results

Concentration of Vinyl Chloride in Different Samples

The concentration of vinyl chloride in the analyzed samples was assessed to facilitate the formulation of conclusions and assumptions during the experiment. Figure 6 established concentrations which were compared to the authorized limit of vinyl chloride in water, set at 0.002 mg/L [2]. The analysis revealed that the samples collected from East Palestine, Chicopee, MA, and North Haven exhibited concentrations of vinyl chloride that exceeded the permissible limit in water. These findings serve as a crucial foundation for subsequent testing and further analysis in order to comprehensively understand the implications and potential risks associated with the elevated levels of vinyl chloride in these locations.

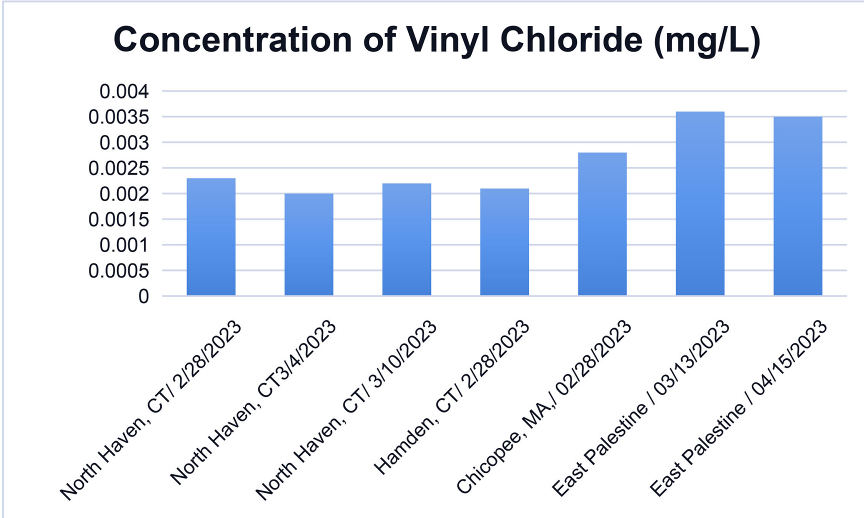


Figure 6. The graph illustrates a comparison of the concentration levels in mg/L for each sample versus the location of samples.

14. Analysis of pH

The analysis of the collected data revealed significant changes in pH levels in precipitation over time and across different locations. The pH values exhibited variations both in the immediate aftermath of the incident and in the subsequent days, weeks and months. These variations provided valuable insights into the long-term consequences of the train derailment and the release of hazardous chemicals.

The spatial analysis demonstrated variations in pH levels at different distances from the incident site. Samples collected closer to the incident site exhibited lower pH values, indicating increased acidity, while samples collected farther away showed relatively higher pH values. This spatial pattern highlighted the localized impact of the incident on precipitation acidity.

The temporal analysis revealed a gradual normalization of pH levels over time. The pH values in the immediate aftermath of the incident were significantly lower than the baseline values, indicating increased acidity. However, as time progressed, the pH levels approached the neutral range, suggesting a recovery process. This temporal pattern provided insights into the duration and extent of the environmental impact caused by the incident.

The statistical analysis, including ANOVA tests, confirmed the significance of various factors in influencing precipitation acidity. The number of days since the incident, location of sample collection, and storage duration of the samples all showed statistically significant effects on pH levels. These findings emphasized the importance of considering these factors when assessing the environmental and health implications of similar incidents in the future.

The analysis presented provides strong evidence of a significant difference between the method of measurement and the days since the Palestine incident, (**Figures 5(a)-(d)**). The analysis of variance confirms this, with p-values for both factors being less than 0.000, indicating a highly significant difference. The coefficients reveal a clear distinction between samples collected at 26 and 30 days, while samples collected at 36 days have minimal influence on the overall p-value. It is important to consider both the method of measurement and the timing of data collection when interpreting the observed differences.

To assess the adequacy of the model, diagnostic plots of the residuals are examined. These plots provide insights into the normality of the residuals, constant variance, and potential correlations. By scrutinizing these plots (**Figure 7**), it is determined that the assumptions underlying the general linear model hold true, confirming the validity of the ANOVA results.

Tukey's Pairwise Comparisons method is used to evaluate mean relationships between different factor levels. The results of the Tukey analysis (**Figures 8(a)-(d)** and **Tables 6(a)-(c)**) allow for the establishment of groupings based on the location of samples, days post-Palestine, and method of data collection. The analysis reveals that there is no significant difference among the locations where samples are collected. However, significant differences are observed between certain pairs of days post-Palestine, indicating potential variations in precipitation composition over time. Additionally, a clear and significant difference is evident among the different methods used to determine pH levels, highlighting the limitations of Litmus paper for precise measurements.

The main effects plot (**Figure 9**) shows the influence of each factor on the response variable. It is observed that the location factor does not have a main effect, while the days since Palestine, Ohio, and method factors do show main effects. The method factor exhibits a stronger main effect, indicating its greater influence on the pH of precipitation.

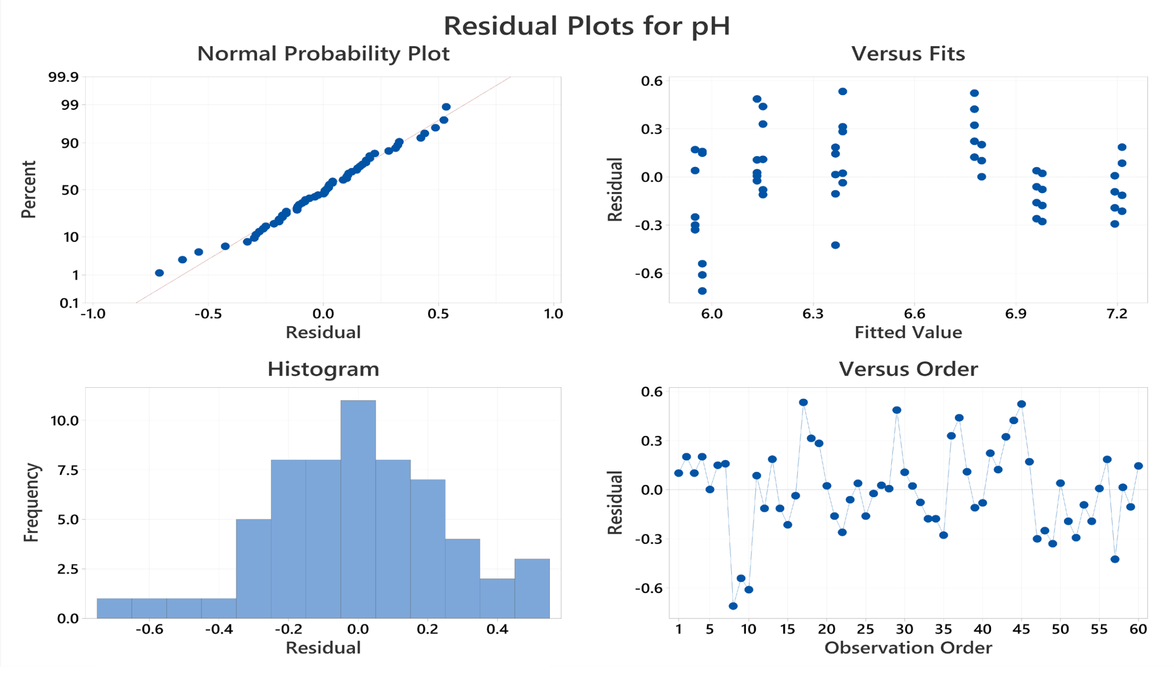
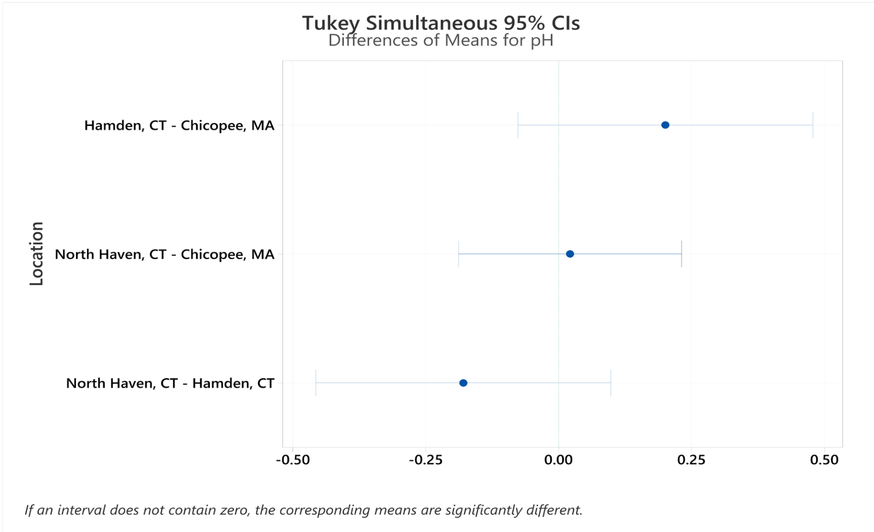
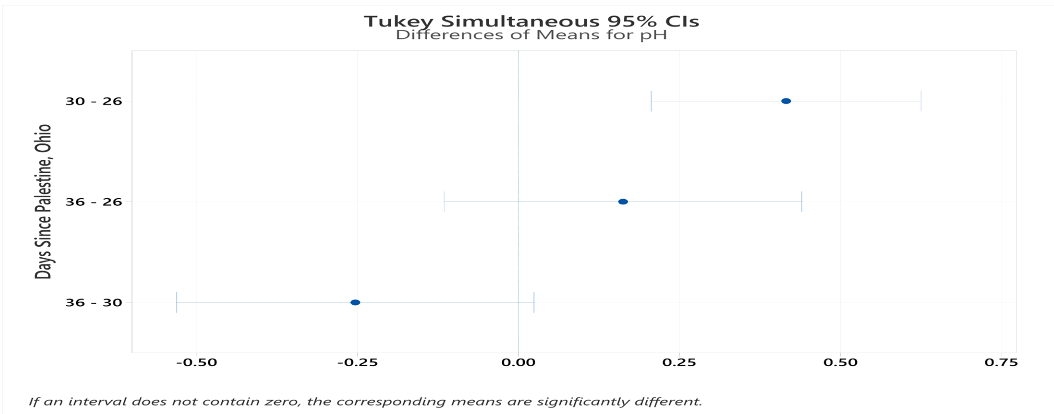


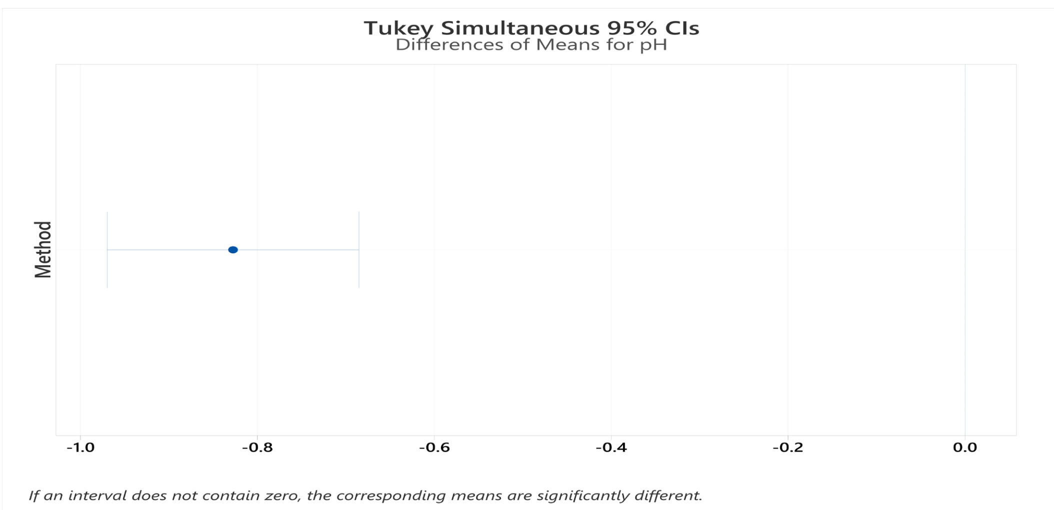
Figure 7. Residual plots for all data points.



(a)



(b)



(c)

Figure 8. (a) Tukey pairwise comparison assuming 95% confidence by locations; (b) Tukey pairwise comparison assuming 95% confidence by days post-Palestine Ohio; (c) Tukey pairwise comparison assuming 95% confidence by method of measuring pH.

Table 6. (a) Tukey pairwise comparisons by location; (b) Tukey pairwise comparison by days post-Palestine Ohio incident; (c) Tukey pairwise comparison by method of pH measurement.

(a)

Grouping Information Using the Tukey Method and 95% Confidence

Location	N	Mean	Grouping
Hamden, CT	10	6.75658	A
North Haven, CT	30	6.57733	A
Chicopee, MA	20	6.55583	A

(b)

Grouping Information Using the Tukey Method and 95% Confidence

Days Since Palestine, Ohio	N	Mean	Grouping	
30	20	6.85283	A	
36	10	6.59958	A	B
26	30	6.43733		B

(c)

Grouping Information Using the Tukey Method and 95% Confidence

Method	N	Mean	Grouping	
Litmus	30	7.04358	A	
Meter	30	6.21625		B

Means that do not share a letter are significantly different.

Residual Plot

The residuals, which represent the discrepancy between the observed and fitted values, serve as an estimate of the error in the general linear model. To evaluate the adequacy of the model, several diagnostic plots are examined. The normal probability plot of residuals displays a straight line, and the central value points should align with this line, indicating that the errors follow a normal distribution. The histogram plot examines the distribution of the residuals' variances, and a symmetric bell shape evenly distributed around the zero mark signifies a normal distribution. The residual vs. fit plot is utilized to verify constant variance, and if the plot appears structureless with no discernible patterns, it indicates a constant variance. Lastly, the residuals vs. order plot presents the residuals in the order of data collection and provides insights into potential correlations and independence.

Based on the mentioned criteria and the graphs presented in Figure 7, it is apparent that the assumptions hold true, affirming the validity of the ANOVA results [8].

15. Multiple Comparison—Tukey: Initial Testing

In experiments involving numerous factor levels, it is crucial to assess the similarities between different factors. Tukey's Pairwise Comparisons method is employed to evaluate the mean relationships among the factor levels. By utilizing the mean values and the 95% confidence interval, we can compare the pairings between factors. The results of the Tukey analysis, as depicted in (**Figures 8(a)-(d)** and **Tables 6(a)-(c)**), enable us to establish groupings based on the location of samples, days post-Palestine, and method of data collection, respectively.

Drawing from the analysis depicted in **Figure 8(a)**, no noteworthy distinction is discernible across the three pairings. This assertion finds support in the fact that the confidence intervals for all pairings encompass a mean difference of zero. Consequently, there exists negligible variability in precipitation pH based on the sampling locale. Various factors contribute to this outcome, with a primary factor being that all sampled locations originate from the same storm front. This suggests that the geographical distances between these locations might lack the significance necessary to yield discernible dissimilarities in precipitation composition. Furthermore, this infers that the storm front carried precipitation with comparable particulate or contaminant concentrations across the diverse sampling sites.

Turning to the observations gleaned from **Figure 8(b)**, no statistically significant contrast is evident between the pairings of 36 days and 26 days, along with 36 days and 30 days. In contrast, a statistically significant difference emerges between the datasets of 30 days and 26 days. This incongruity could potentially be traced back to multiple factors. It's plausible that a considerable amount of precipitation, following the storm on February 3rd, triggered a chlorine release, consequently leading to a lower mean pH for samples collected at 26 days in comparison to 30 days. However, despite this assertion, the findings indicate no substantial difference between these two pairings. This discordance can be attributed to the smaller sample size at 30 and 36 days, which could inadvertently skew the means and result in an inadequate representation of the overall population.

With respect to the insights extracted from **Figure 8(c)**, a conspicuous and statistically significant divergence is discernible among the different methods employed for pH determination. This outcome can be ascribed to the intrinsic nature of Litmus paper, primarily designed to provide a general pH indication rather than precise measurements. While Litmus paper holds historical significance and has served as a quick acid-base indicator, it might not offer the highest level of precision when exact measurements are essential.

16. Main Effects Plot

The main effect refers to the influence of a single factor on a response variable. The mean effects plot shows the relationship between the mean values and different levels of the factors. A horizontal line indicates the absence of a main effect, while a non-horizontal line suggests the presence of a main effect. The strength of the main effect is determined by the slope of the line, with a steeper slope indicating a stronger effect. In **Figure 9**, the main effects plot for pH reveals that the location factor does not have a main effect (horizontal line), while the days since Palestine, Ohio, and method factors do show main effects. The method factor exhibits a larger slope, indicating a stronger main effect. [8]

17. Second Block of Testing

General Linear Model

Based on a significance level of 0.05, a statistically significant difference is observed for the Jar Brands in the pH of precipitation. However, there are limitations in drawing conclusions from this analysis. The irregularity of factor levels and sample sizes led to the use of a custom factorial design, but only the Days Post-Palestine Incident factor remained in the analysis. The General Linear Model method was also applied, resulting in only the Jar Brand factor being considered (**Table 7**). Individual One-Way ANOVAs were performed using the Tukey Simultaneous Method to assess the impact of each factor on precipitation pH. The adequacy of the model was checked as well. Notably, water quality testing strips were excluded from the analysis due to their qualitative nature, providing results in terms of "SAFE" and "UNSAFE" rather than numerical values. The most significant factor identified was QUAT/QAC, requiring further research to evaluate its potential toxicity. The limitations of the test strips and their general nature prevented a definitive conclusion from being drawn using Minitab analysis.

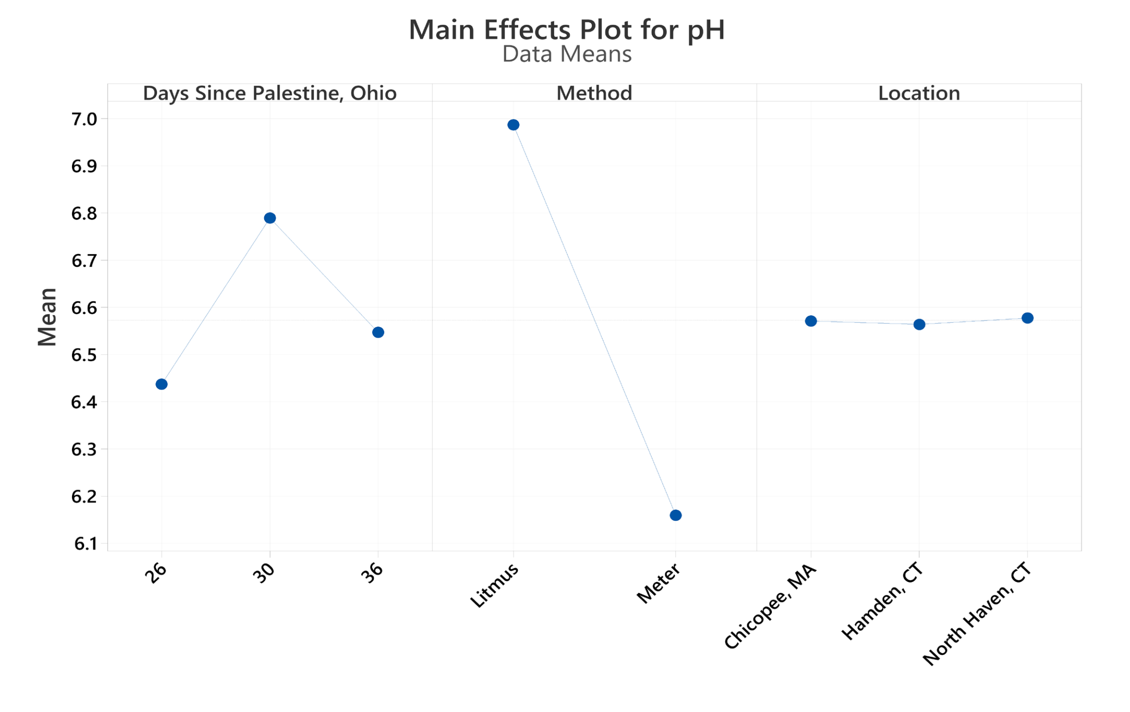


Figure 9. Main effects plot of the location, days Post-Palestine, and method of measuring pH.

Table 7. Numerical general linear model output from minitab for the first and second block of data collection.

Analysis of Variance

Source	DF	AdjSS	AdjMS	F-Value	P-Value
Jar Brand	3	6.995	2.33155	4.95	0.004
Error	61	28.736	0.47108		
Lack-of-Fit	7	26.572	3.79602	94.73	0.000
Pure Error	54	2.164	0.04007		
Total	64	35.731			

18. Model Adequacy Check

In the One-Way ANOVA analysis, the adequacy of the model is assessed by examining several assumptions. These assumptions include the data fitting a normal distribution, having constant variance, each factor being independent, and the data being randomly sampled. To evaluate these assumptions, residual plots (depicted in **Figures 10(a)-(d)**) are used. The residual plots help assess whether the assumptions hold by examining the distribution of residuals, detecting patterns or trends that indicate violations of assumptions, and assessing the randomness of the sampling process. These assumptions are important for ensuring the reliability and validity of the ANOVA analysis results [8].

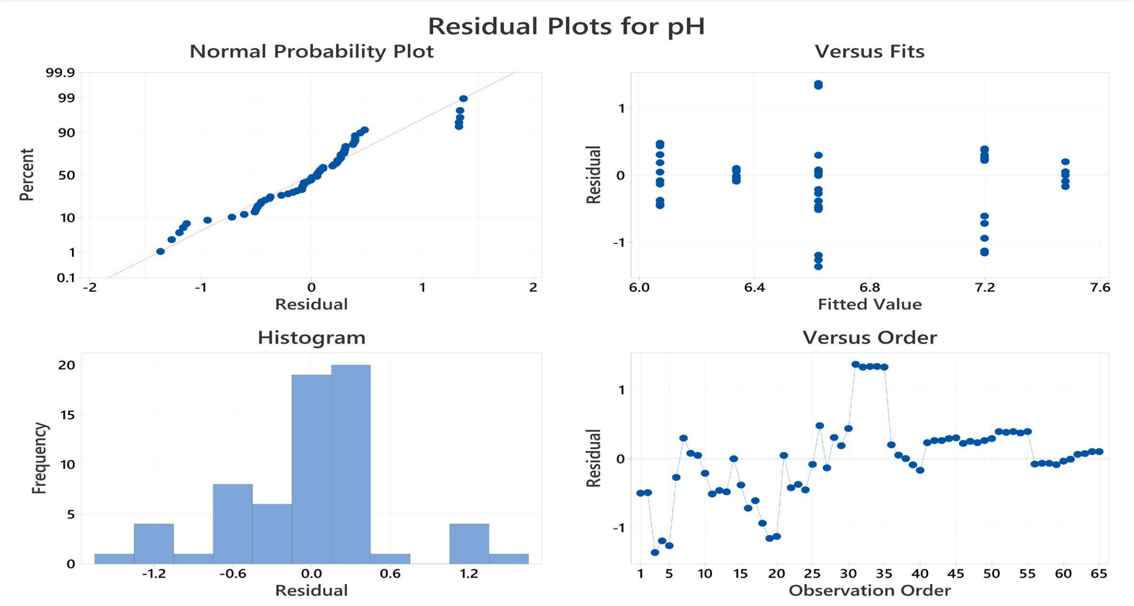
After examining it is evident that the model satisfies the normality assumptions. First, after looking at all the normal probability plots and histograms, the distribution is approximately normal thus the first assumption is fulfilled. The second assumption, that the data is independent, is clear after examining the versus order graphs from the figures. Finally, the variance is approximately equal which can be seen in the versus fits plots (**Figures 10(a)-(d)**).

19. Multiple Comparison—Tukey: Final Testing

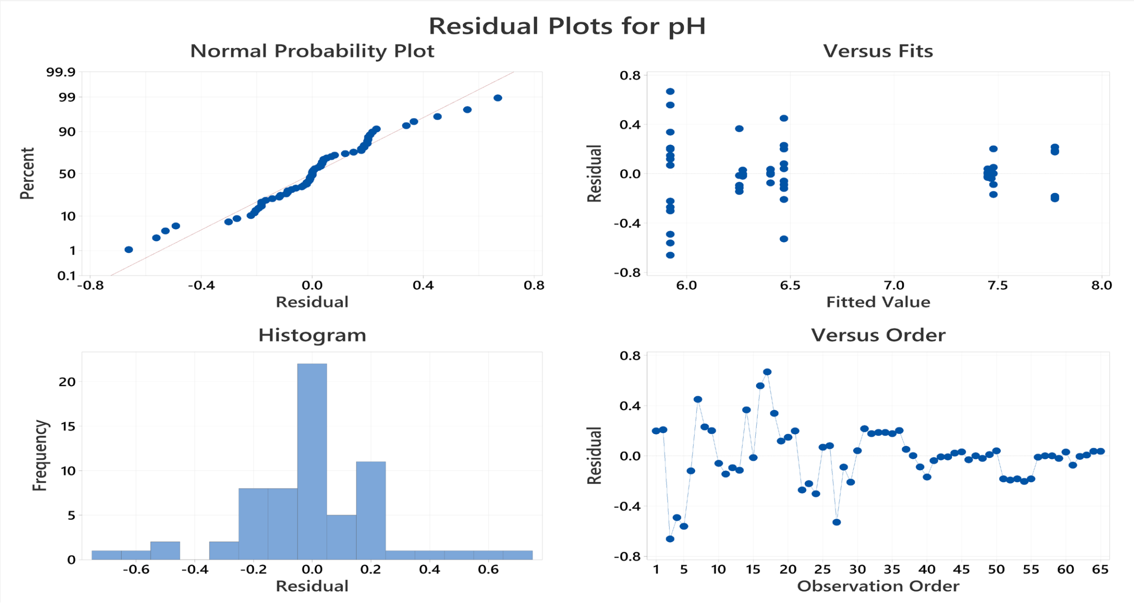
Tukey's Pairwise Comparisons method is employed to assess mean relationships when dealing with numerous factor levels. This approach utilizes the mean and the 95% confidence interval to facilitate comparisons between different pairings.

Based on One-Way ANOVA, the p-value is 0.000, indicating the rejection of the null hypothesis, and the location of sample collection is found to significantly impact the pH of precipitation (**Figure 11(a)**). Using the Tukey Simultaneous method, the locations are divided into three groups (A, B, C), with some locations belonging to multiple groups. These groupings suggest statistically significant differences between certain locations (**Figure 8(a)**). Factors such as proximity to metropolitan and industrial areas, as well as air quality, may contribute to the observed variations in precipitation pH. However, the inclusion of Greenfield in the same group as North Haven and Hamden, despite its distinct characteristics, may be influenced by the low sample size, potentially not representing the population mean accurately.

Based on One-Way ANOVA, the p-value is 0.000, indicating the rejection of the null hypothesis, and the number of days after the East Palestine, Ohio incident is found to have a significant influence on the pH of precipitation. The factor levels are grouped into three categories (A, B, C), but unexpectedly, there is no discernible pattern in the groupings (**Table 8(b)**). The original hypothesis that closer samples would have lower pH levels is not supported. The lack of a linear logic in the groupings may be attributed to asymmetric sample collection, with different operators collecting samples from various storm fronts on different days (**Figure 11(b)**). Consequently, the interactions between the factors cannot be determined due to the asymmetric sample collection.



(a)



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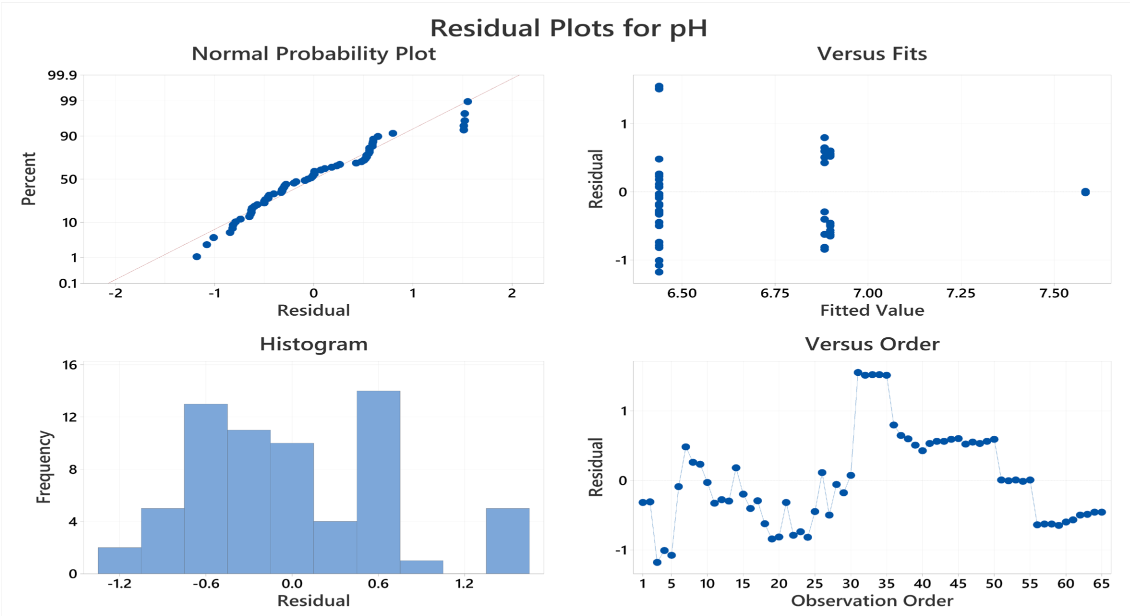
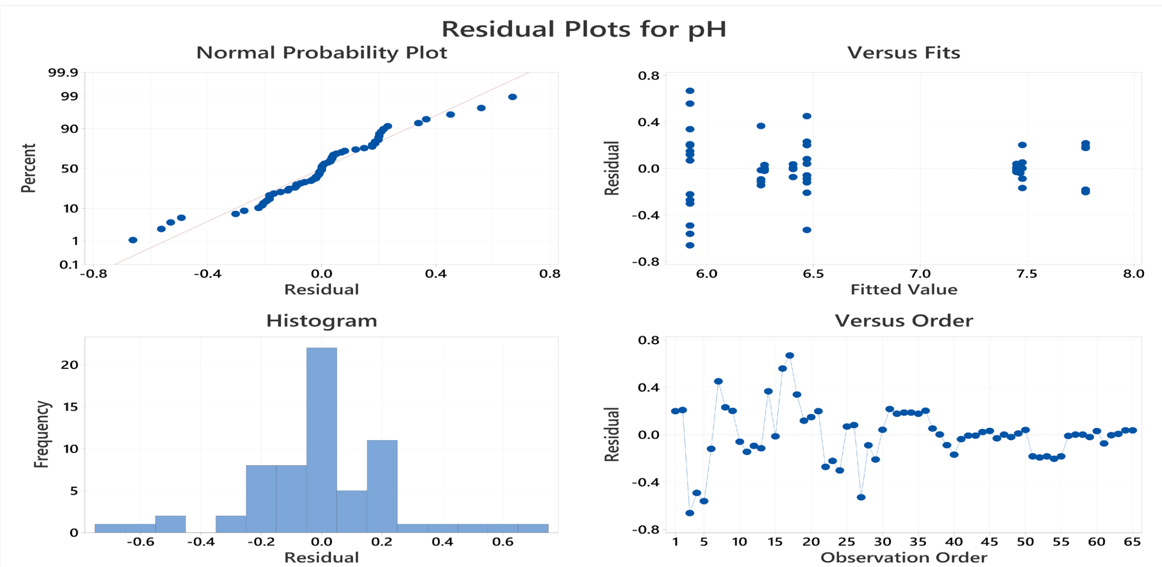


(c)



(d)

Figure 10. (a) Residual Plot of the Location including pH data from the initial and second block of testing; (b) Residual Plot of the days since the East Palestine, Ohio incident including pH data from the initial and second block of testing. (c) Residual Plot of the days the sample was left sitting prior to data collection including pH data from the initial and second block of testing. (d) Residual Plot of the jar brand including pH data from the initial and second block of testing.

The One-Way ANOVA analysis resulted in a p-value of 0.000, indicating that the null hypothesis is rejected, and the factor of days between sample and data collection is found to have a significant impact on the pH of precipitation (Table 8(c)). However, similar to the days post-Palestine, Ohio factor, the grouping of factor levels does not follow a linear pattern. It is possible that this factor is interconnected with other factors, but due to the asymmetry of the data collection, the extent of this interrelation cannot be quantified as seen in (**Figure 11(c)**).

Based on the results of the One-Way ANOVA analysis, a p-value of 0.004 was obtained, leading to the rejection of the null hypothesis and indicating that the brand of mason jar has a significant effect on the pH of precipitation. Notably, no nuisance factors were identified as their effects on the response variable were deemed statistically insignificant (**Table 8(d)**).

The division of factors into two groups, A and B, does not offer a logical explanation for the observed differences, as there should be no inherent disparity in glass composition among manufacturers that would directly influence the pH of the samples. Nevertheless, similar to the other factors, the choice of jar brand is linked to the location due to different operators using different brands, resulting in some overlap. For instance, both North Haven and Chicopee operators utilized Ball brand mason jars, establishing a connection between these two locations. However, as previously discussed, the extent of this linkage remains unquantifiable due to the unbalanced sampling design (**Figure 11(d)**).

Table 8. (a) Tukey pairwise comparison by location of sample collection; (b) Tukey pairwise comparison by days post-Palestine Ohio incident; (c) Tukey pairwise comparison by days between sample and data collection; (d) Tukey pairwise comparison by Jar Brand.

(a)

Grouping Information Using the Tukey Method and 95% Confidence

Location	N	Mean	Grouping		
Greenfield, MA	5	7.4780	A	B	
Hamden, CT	20	7.197	A		
North Haven, CT	20	6.621		B	C
West Haven, CT	10	6.3370			C
Chicopee, MA	10	6.072			C

(b)

Grouping Information Using the Tukey Method and 95% Confidence

Days Since Palestine, Ohio	N	Mean	Grouping		
57	10	7.7730	A		
28	5	7.4780	A		
38	5	7.4680	A		
39	5	7.4500	A		
29	10	6.4690		B	
37	5	6.4040		B	
36	5	6.27000		B	C
35	5	6.2540		B	C
25	15	5.921			C

(c)

Grouping Information Using the Tukey Method and 95% Confidence

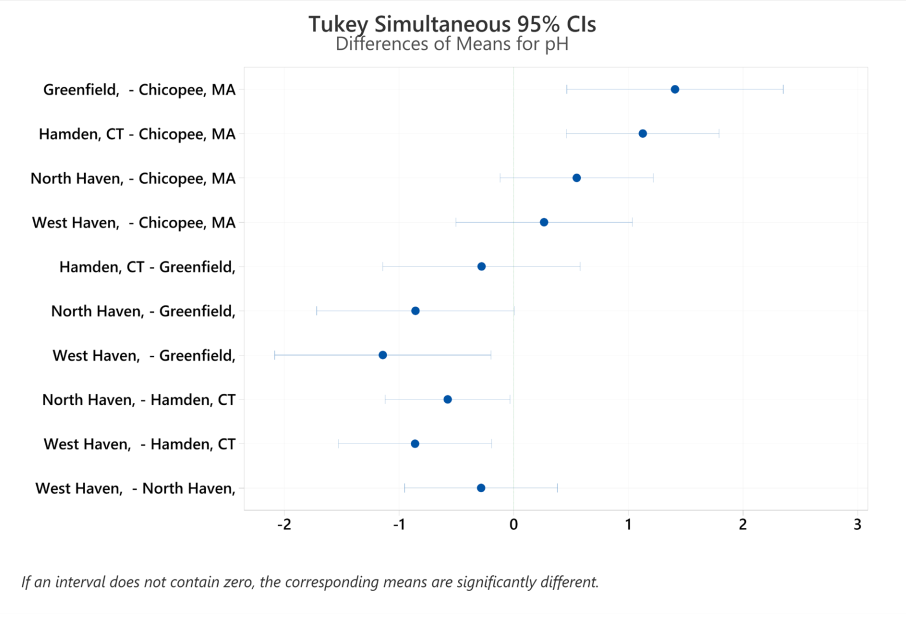
Days Sitting in a jar	N	Mean	Grouping		
14.00	10	7.7730	A		
43.00	5	7.4780	A		
33.00	5	7.4680	A		
32.00	5	7.4500	A		
9.00	10	6.4690		B	
34.00	5	6.4040		B	
35.00	5	6.27000		B	C
3.00	5	6.2540		B	C
13.00	15	5.921			C

(d)

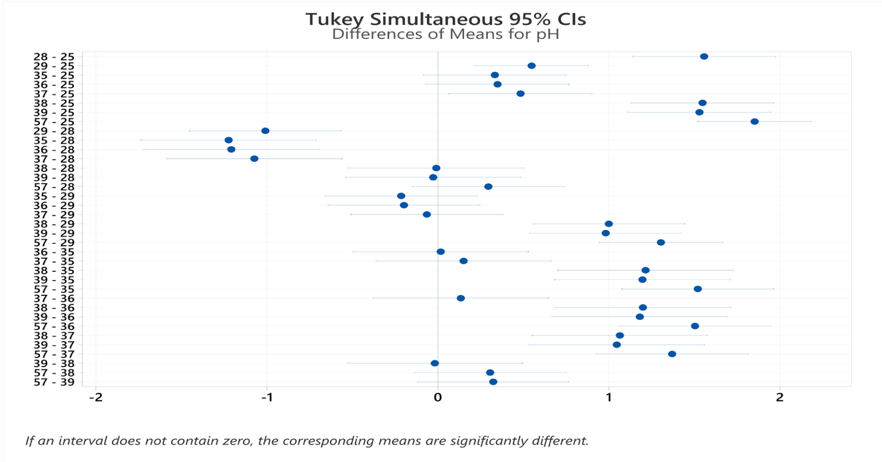
Grouping Information Using the Tukey Method and 95% Confidence

Jar Brand	N	Mean	Grouping	
JoyJolt	5	7.58400	A	
Kamota	20	6.898	A	B
Kilner	10	6.883	A	B
Ball	30	6.438		B

Means that do not share a letter are significantly different.



(a)



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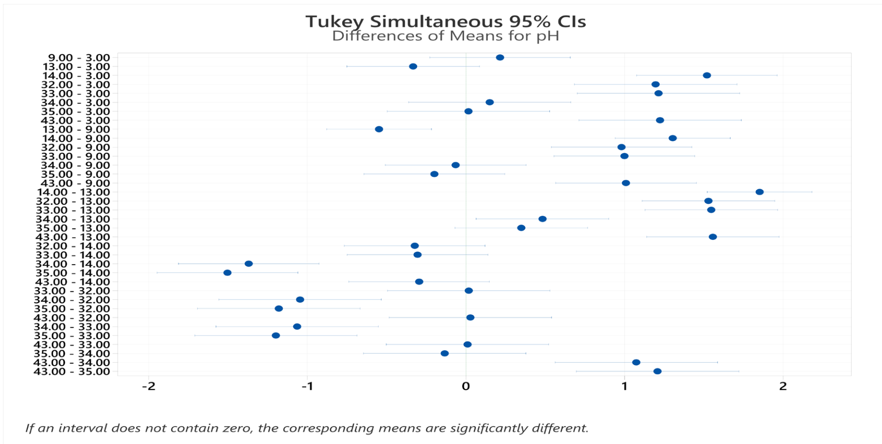
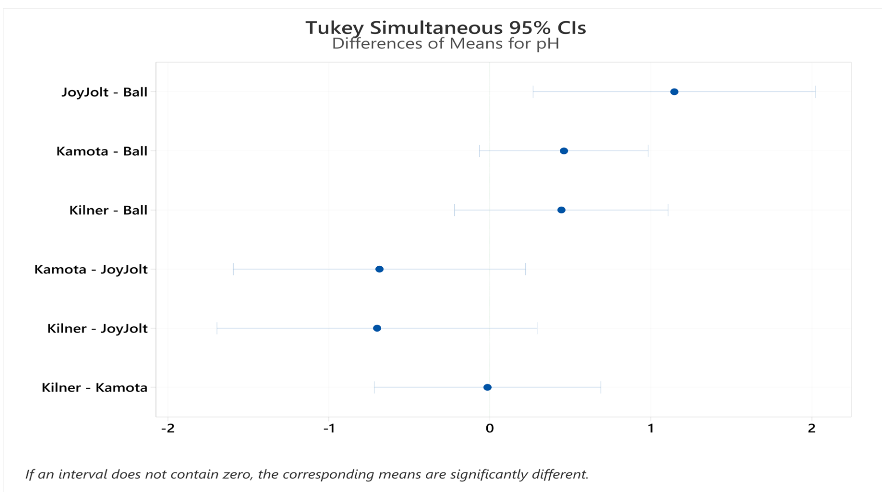


(c)



(d)

Figure 11. (a) Tukey pairwise comparison assuming 95% confidence by location of sample collection; (b) Tukey pairwise comparison assuming 95% confidence by days since Palestine, Ohio; (c) Tukey pairwise comparison assuming 95% confidence by days between sample and data collection; (d) Tukey pairwise comparison assuming 95% confidence by Jar Brand.

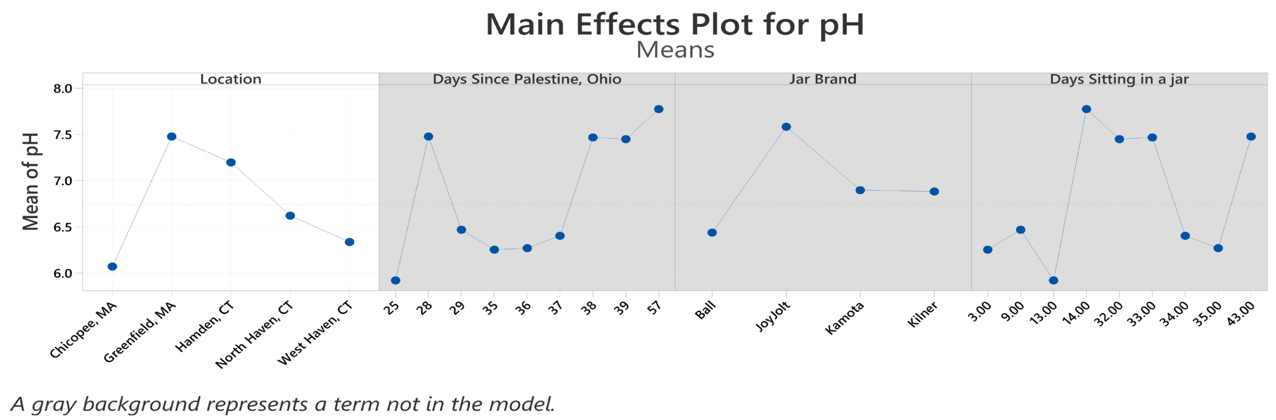


Figure 12. Main effects plot for pH.

Main Effects Plot

In Figure 12, the main effects plot of the failed custom factorial design illustrates the impact of each factor on the mean pH of the collected samples. The Location factor is presented in white, while the other three factors are shown in grey to indicate that their effects were not estimable and thus not included in the model but are included in the plot for reference. Despite this limitation, the factorial model exhibits the highest R2-value of 90.12%, suggesting a reasonably representative model considering the substantial variability associated with weather-based experiments. In contrast, the One-way ANOVA models display lower R2-values ranging from 37.15% for location to 19.58% for jar brand. The only exception to the low R2-values is the ANOVA for days between sample and data collection, which shares the exact same value as the factorial design.

20. Discussion and Conclusion

In summation, this meticulous assessment of precipitation acidity subsequent to the train derailment and vinyl chloride release in East Palestine, Ohio, has yielded invaluable insights into the complex nexus between the incident and its profound ramifications for both the environment and public health. The identification of heightened vinyl chloride concentrations surpassing established thresholds in local water sources underscores potential risks not only for East Palestine but also for its broader ecological fabric.

These findings, while illuminating, merely represent a preliminary stride towards comprehending the multifaceted risks engendered by elevated vinyl chloride levels. The study's revelations demand further comprehensive testing and in-depth analysis to unveil the full spectrum of hazards tethered to such escalated concentrations. The study adeptly highlights the imperativeness of adept environmental monitoring and proactive mitigation strategies, essential components in orchestrating a responsive shield against analogous occurrences.

This study resoundingly emphasizes the profound influence of environmental perturbations on human health, particularly their interrelation with conditions such as cancer and chronic ailments. The insights garnered advocate for evidence-centered decision-making that extends its purview to encompass policymakers, environmental stewards, and the pantheon of stakeholders constituting health and environmental agencies. Moreover, it is imperative that subsequent inquiries delve into the intricate mechanics underpinning the incident's long-term repercussions, spanning ecosystems, human well-being, and crucial infrastructural facets.

In its totality, this study's contributions transcend the realms of scientific exploration, affording an enriched understanding of disaster management strategies in kindred scenarios. By engendering a reservoir of knowledge that informs decision-making and bolsters response strategies within the spheres of health and environment, this study seamlessly bridges the chasm between the complex choreography of industrial mishaps and the profound impacts on public well-being.

Recommendations

1) Temporal Dynamics Analysis: Extend the investigation's temporal horizon to unravel the transient dynamics of vinyl chloride dispersion and its subsequent environmental and health effects. Employ advanced modeling techniques to simulate the compound's long-term behavior, aiding in the formulation of targeted strategies.

2) Metabolomic Profiling: Conduct metabolomic profiling on affected organisms and local biota to discern latent biochemical responses elicited by the vinyl chloride release. Integrating advanced omics technologies can unearth subtle molecular perturbations, enriching our comprehension of the incident's systemic impact.

3) Epidemiological Projections: Undertake epidemiological projections to anticipate the long-range health consequences on the local populace. By integrating demographic and health data, predictive modeling can facilitate preemptive healthcare measures and resource allocation.

4) Ecotoxicological Assessments: Extend the scope of inquiry to encompass comprehensive ecotoxicological assessments. Exploit advanced biomonitoring techniques to gauge the incident's ripple effect across trophic levels, highlighting indirect ecological consequences.

5) Multi-Scalar Modeling: Develop multi-scalar modeling frameworks that bridge molecular, individual, and ecosystem-level responses. Such integrative models enable a holistic understanding of the incident's cascading impacts, facilitating targeted intervention strategies.

6) Integrated Governance Framework: Establish an integrated governance framework that seamlessly integrates insights from biomedical, environmental, and engineering disciplines. Foster interdisciplinary collaboration to expedite holistic decision-making and implementation.

7) Innovative Remediation Approaches: Explore innovative remediation strategies, such as nanoremediation or bioaugmentation, tailored to the specific attributes of vinyl chloride contamination. Employ cutting-edge technologies to expedite effective site remediation.

8) Health Surveillance System: Institute a comprehensive health surveillance system to monitor long-term health effects and ascertain the emergence of latent conditions linked to vinyl chloride exposure. Leverage advanced health informatics for real-time data analysis.

9) Longitudinal Ecological Studies: Initiate longitudinal ecological studies that span multiple years to capture the intricate ecological recovery trajectory. This endeavor will inform adaptive management strategies that align with evolving ecosystem dynamics.

10) Global Best Practices Exchange: Facilitate international knowledge exchange forums to disseminate findings and best practices in managing industrial accidents of this nature. Collaborate with global experts to enhance collective preparedness.

In closing, these recommendations transcend the conventional confines of response and mitigation. They advocate for a proactive, integrative, and multidimensional approach that acknowledges the intricate web of interactions forged by such incidents, enabling us to not only comprehend their immediate impacts but also anticipate their far-reaching consequences.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Hauser, C. (2023) After the Ohio Train Derailment: Evacuations, Toxic Chemicals, and Water Worries. *The New York Times.* https://www.nytimes.com/article/ohio-train-derailment.html

[2] Carlson, C. (2023) Everyone's Talking about East Palestine, Ohio. *The Daily Yonder.* https://dailyyonder.com/everyones-talking-about-east-palestine-ohio/2023/02/22/

[3] Machaieie, H., Silva, C., Oliveira, E., Júnior, H. and Almeida, H. (2020) Variability and Trends of Precipitation in Quelimane, Central Mozambique, and Their Relation to El Niño Southern Oscillation. *Journal of Geoscience and Environment Protection*, **8**, 1-16. http://doi.org/10.4236/gep.2020.87001

[4] Wave, S.J. 16 in 1 Drinking Water Test Kit. https://www.sjwave.com/products/16-in-1-drinking-water-test-kit

[5] Zundel, J. (2023) The pH Scale, Solutions & Buffers. https://study.com/academy/lesson/the-ph-scale-solutions-buffers.html

[6] Department of Health and Human Services, Public Health Service Agency for Toxic Substances and Disease Registry. http://www.atsdr.cdc.gov/

[7] Minitab. Minitab Statistical Software. https://www.minitab.com/en-us/products/minitab/?utm_campaign=BFO+-+US+-+EN&utm_medium=ppc&utm_term=minitab&utm_source=adwords&hsa_net=adwords&hsa_mt=e&hsa_ver=3&hsa_grp=77781447244&hsa_ad=434962183165&hsa_tgt=kwd-298703240867&hsa_cam=2058977188&hsa_acc=4841564033&hsa_src=g&hsa_kw=minitab&gclid=Cj0KCQjw2v-gBhC1ARIsAOQdKY1Dnyej1MaW5cj73MuqAw82P_xVmZzShzQDYhAMkH28V7Q8Y09I2n4aAvOnEALw_wcB#tabs-463bc46f9e-0N9PzglrHm-tab-3

[8] Montgomery, D.C. (2020) Design and Analysis of Experiments. 10th Edition, Wiley, Hoboken.

[9] Helmenstine, A. (2020) What Is Litmus Paper? How to Do the Litmus Test. https://www.thoughtco.com/what-is-litmus-paper-3976018

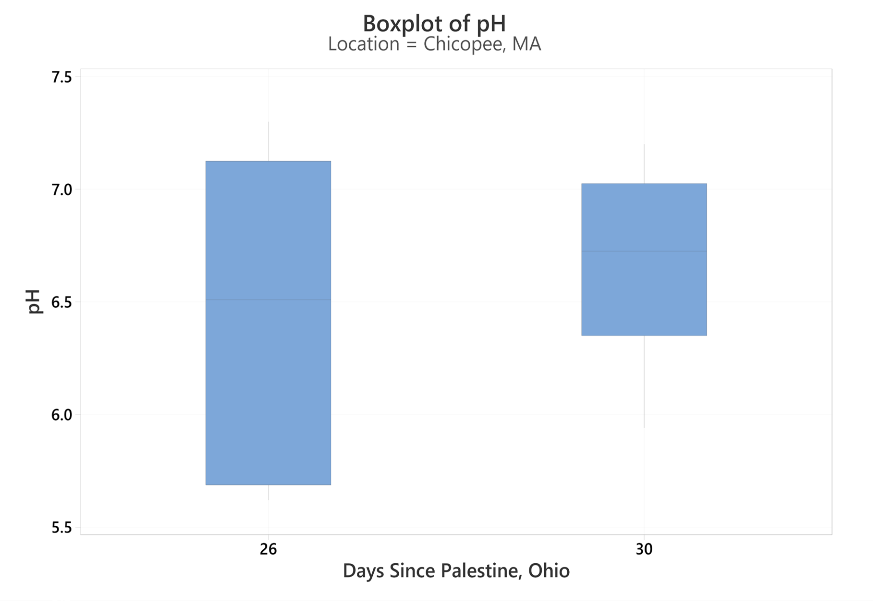
[10] Dhiraj, D., Arpan S. and Pronobesh, C. (2021) Functionalized Carbon Nanotubes: Synthesis, Properties and Applications in Water Purification, Drug Delivery, and Materials and Biomedical Sciences. *Journal of Nanoscale Advances*, **3**, 17-18.

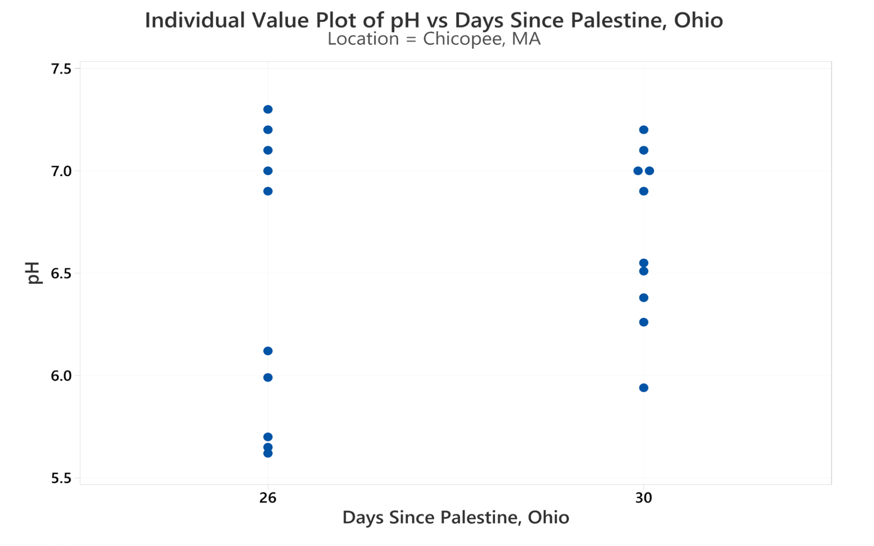
Equipment/Materials

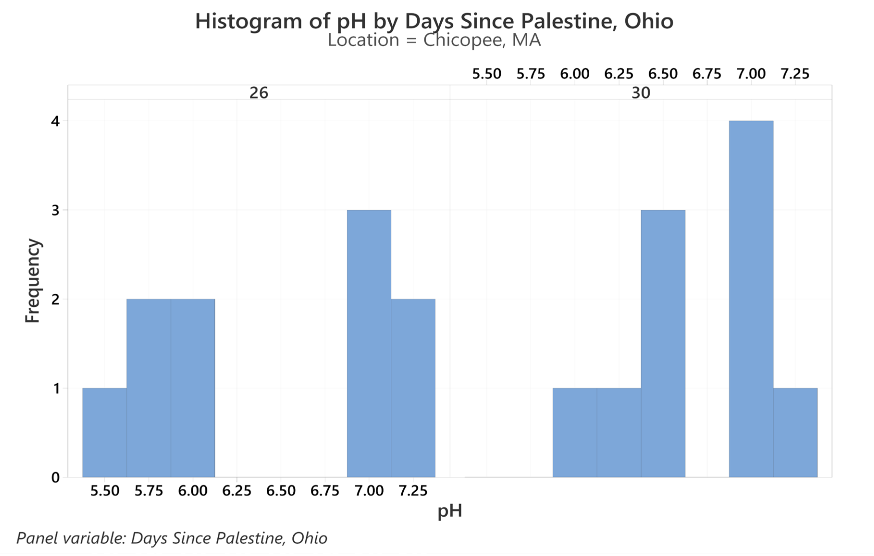
1) Precipitation samples
2) VIVOSUN The pH meter (range 0.00 - 14.00 accuracy ±0.01 pH)
3) Lab Aider Litmus paper
4) Distilled water
5) Meter calibration solutions
6) Gloves
7) Mason jars

Appendix A. Graphical Investigation

The histogram graphs show the central tendency, spread, and shape of the distribution of the data [8]. The horizontal axis (x-axis) is the pH represented by bins and the vertical axis (y-axis) is the frequency of those pH values. The individual plot shows a dot for each observation in its respective group. The y-axis is the data values, and the x-axis is the spread of the points. This plot shows if there are any outliers and its distribution spread. Exploratory plots below are **Figure A1** Chicopee, MA, **Figure A2** Hamden, CT, and **Figure A3** North Haven, CT for round one of testing. **Figure A4**, **Figure A5** from round two of testing.


Boxplot of pH
Location = Chicopee, MA
7.5
7.0
6.5
6.0
5.5
pH
26
30
Days Since Palestine, Ohio


Individual Value Plot of pH vs Days Since Palestine, Ohio
Location = Chicopee, MA
7.5
7.0
6.5
6.0
5.5
pH
26
30
Days Since Palestine, Ohio


Histogram of pH by Days Since Palestine, Ohio
Location = Chicopee, MA
26
30
5.50 5.75 6.00 6.25 6.50 6.75 7.00 7.25
Frequency
4
3
2
1
0
5.50 5.75 6.00 6.25 6.50 6.75 7.00 7.25
pH
Panel variable: Days Since Palestine, Ohio

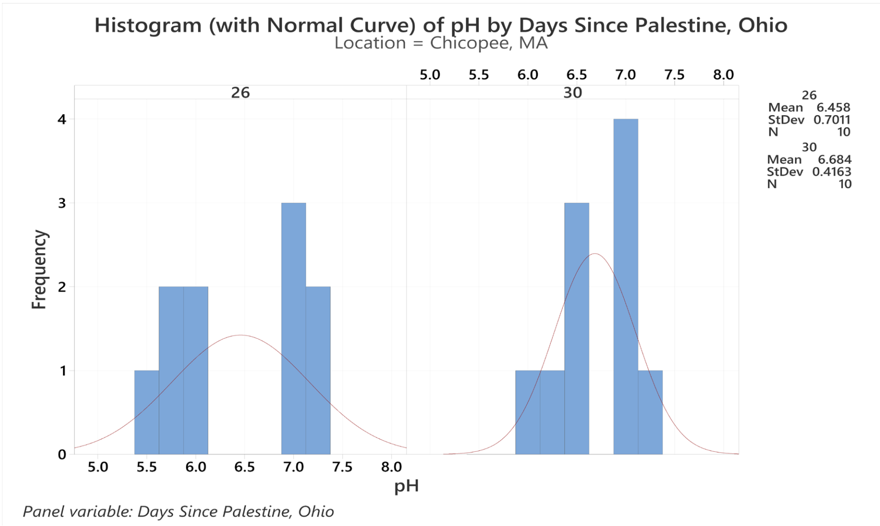
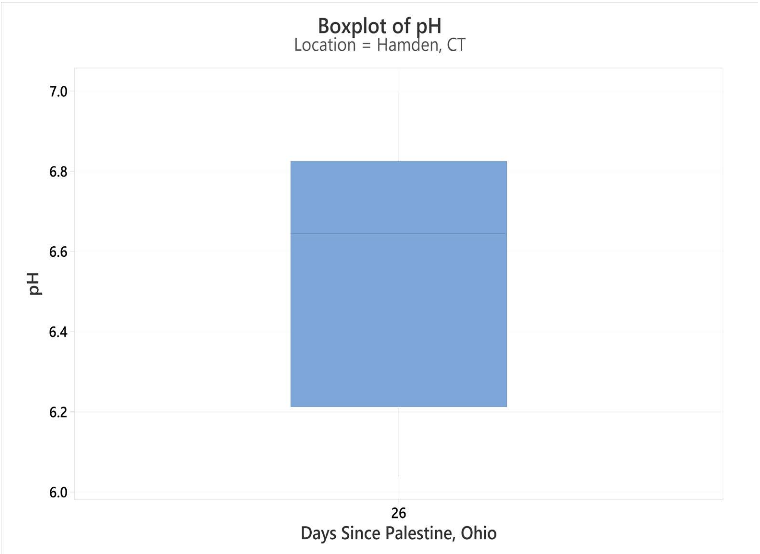
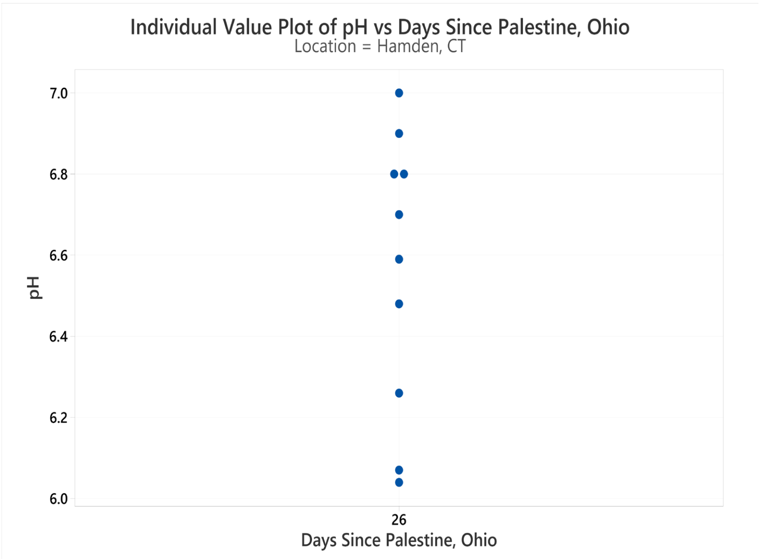
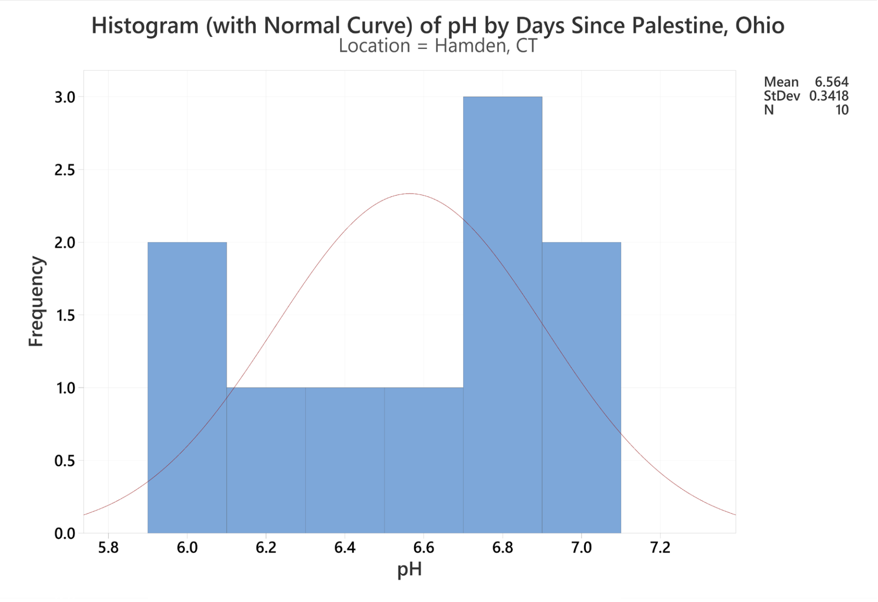


Figure A1. Chicopee, MA.







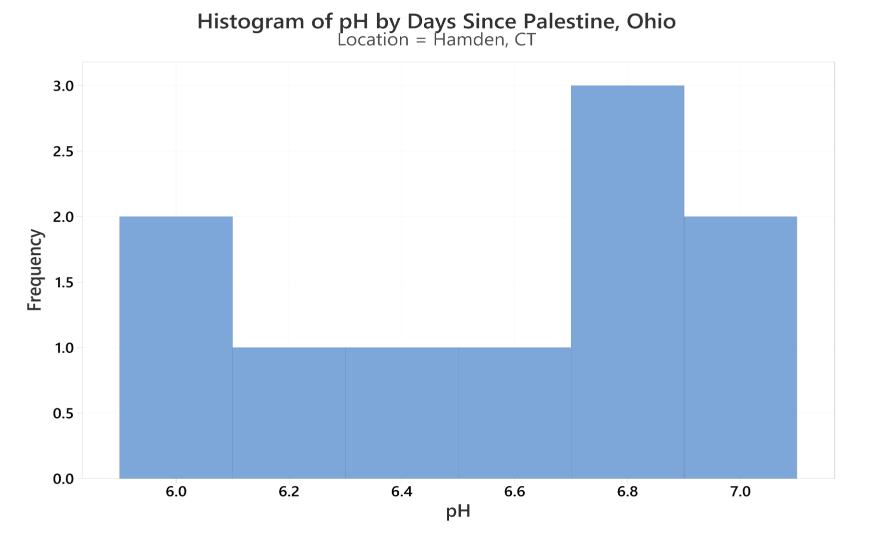
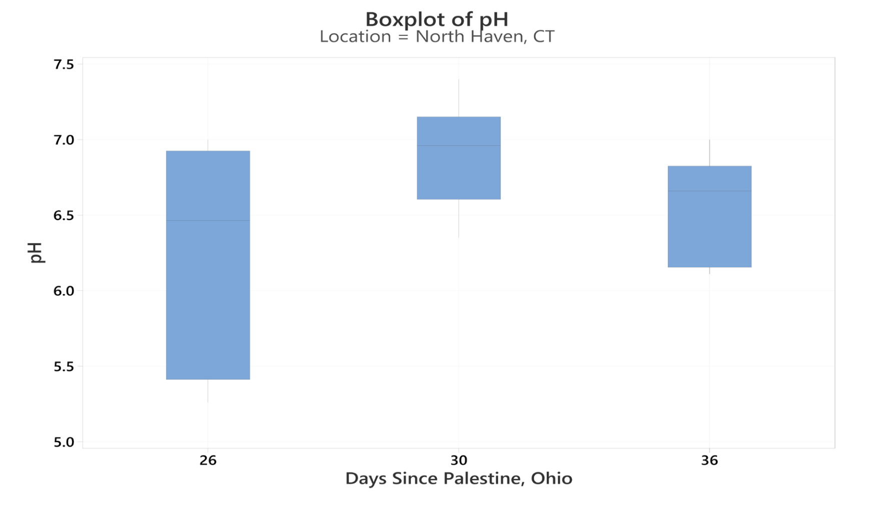


Figure A2. Hamden, CT.



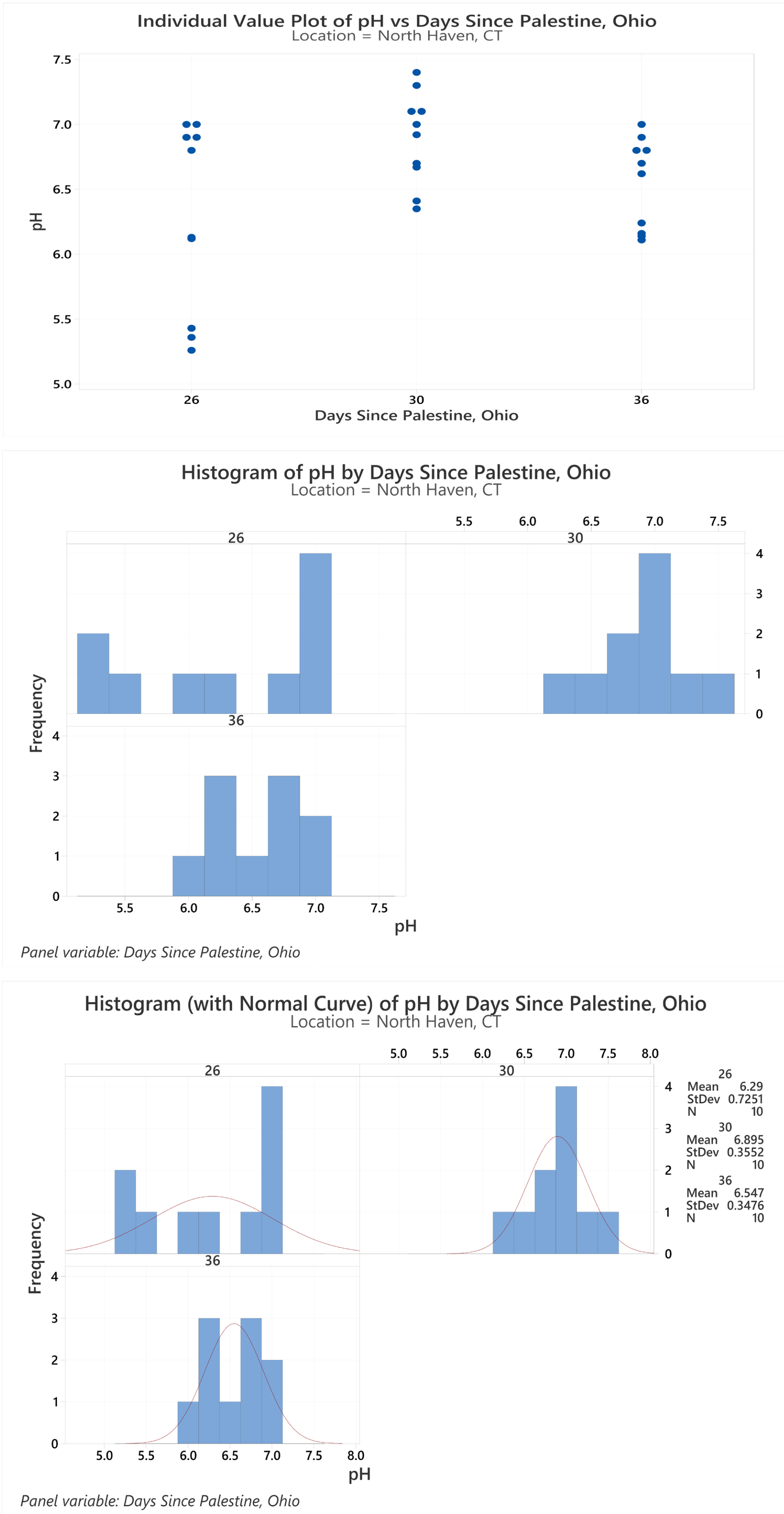
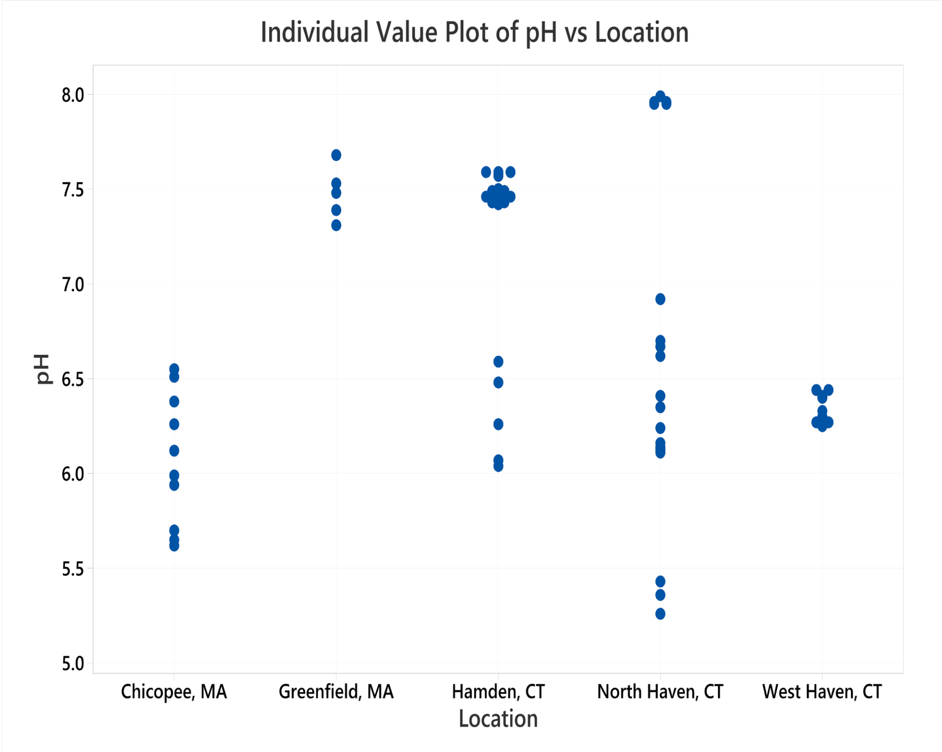


Figure A3. North Haven, CT.



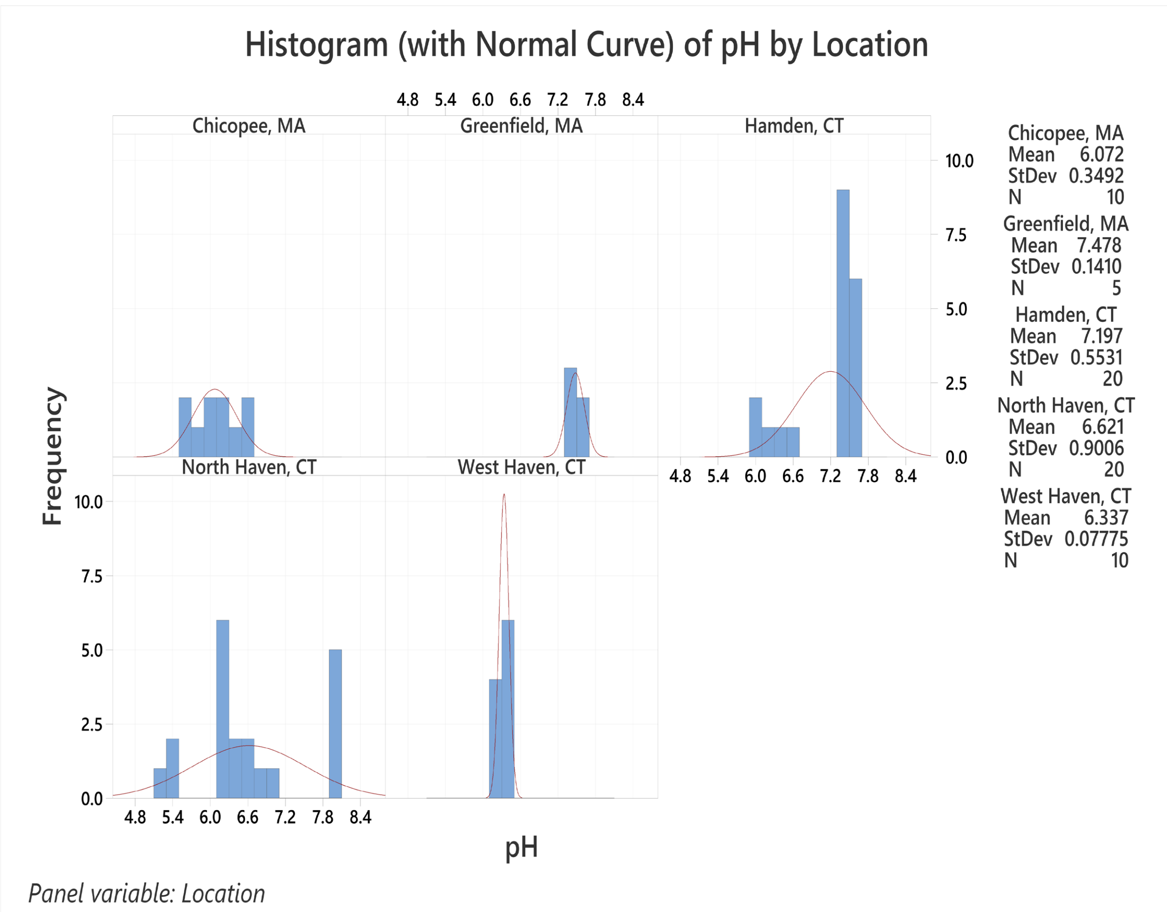


Figure A4. pH by Location.

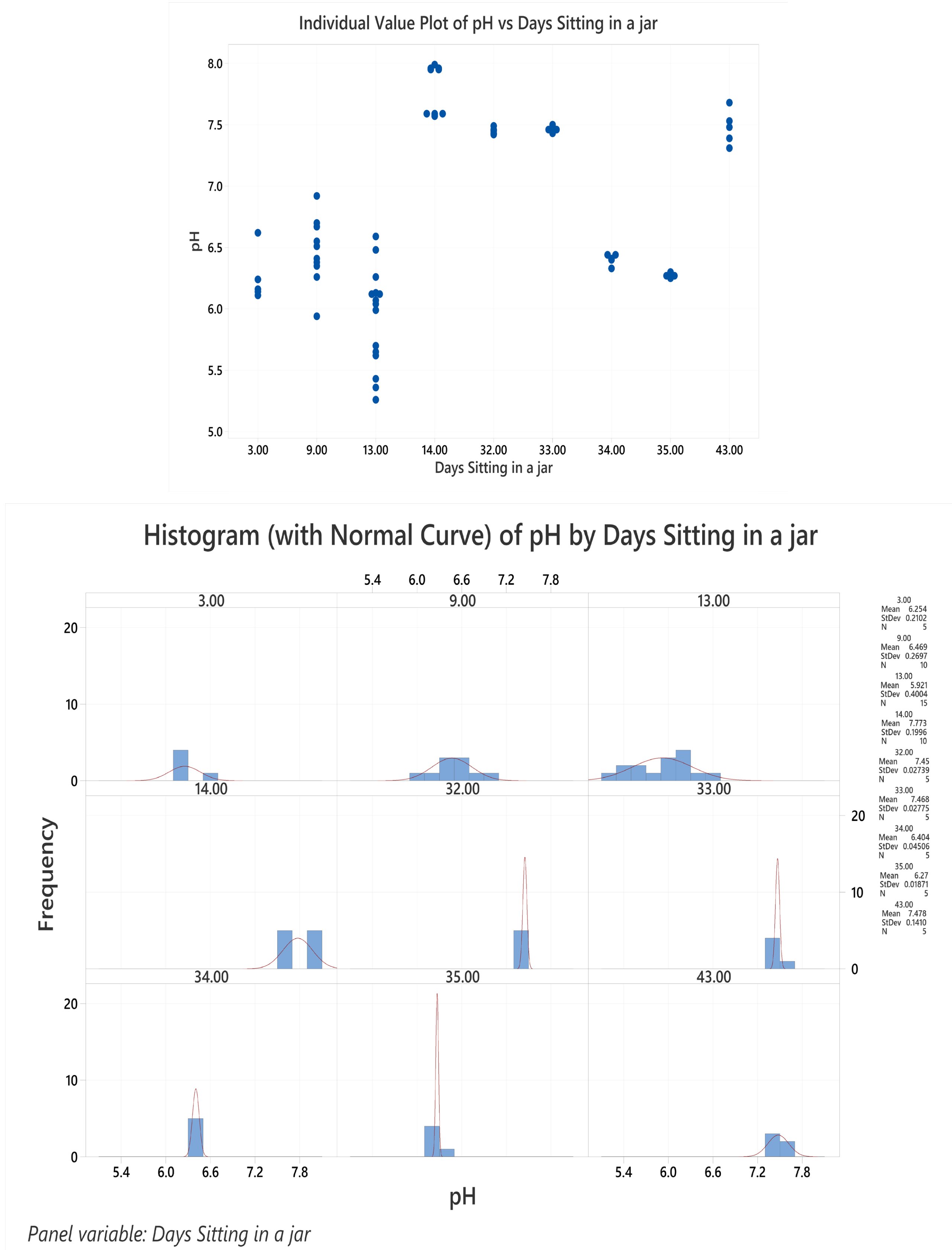


Figure A5. pH by Days Sitting in a Jar.