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Water Quality Assessment

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Abstract

The objective of this report was to analyze the water quality of various residence halls throughout the Northeastern University campus. It was to be determined if there were any significant differences between the different locations throughout the campus and if the data fit within health and safety standards. In conducting this experiment, chlorine and pH sensors were utilized to obtain data. Data from six residence halls were collected with five trials per location, including a seventh data set for a Brita filter. Averages were calculated after the trials were conducted, and statistical analyses were conducted with t-tests and ANOVA tests. The ANOVA test determined that there were statistically significant differences between all the locations of collections. The t-tests indicated that the water sample filtered with the Brita filter had statistically significant differences compared to the unfiltered samples. It was also determined that the chlorine data for every location was within the 4 ppm standard, and that the pH data was all above the 6.5-8.5 standard range which is accounted for by Boston purposely raising their pH levels. It should be noted, though, that the pH data with the Brita filter fell within the safety standard range. There was no correlation between the chlorine data and the pH data.

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4 Problem Statement

Water quality is a crucial subject for public health. High levels of particulates or chemicals can lead to major health concerns for the populations consuming water. With so many students drinking water from campus sources every day, it was valuable to measure the water quality across campus residence halls to verify that the unfiltered water supply was within the CDC, EPA, and governmental guidelines. Unfiltered water samples were tested for pH, chlorine, and lead levels from various residence halls to determine if they were within safe ranges according to governmental health standards. The unfiltered samples would be compared to the levels from a sample filtered through a Brita filter.

5 Introduction

The goal of this study was to determine if water from residence halls on campus was within safe limits of chlorine, pH, and lead levels for regular consumption. Clean and safe drinking water is vital for human health, as certain contaminants and high levels of chemicals can lead to major health complications. Water on a state and town level is tested for radionuclides, biological components, particulates, and known contaminants which pose risks to human health [1]. Due to the limited availability of sensors, only lead levels, pH, and chlorine levels were examined in this study.

Various governmental organizations have compiled guidelines regarding the qualities of safe drinking water. For lead, the EPA has set the maximum contaminant level to be 0 ppm, since any level of lead can be harmful to humans [2]. The EPA has not set a pH range because it is classified as a secondary drinking water contaminant. However, they still recommend a pH range of 6.5 to 8.5 [3]. The CDC states that up to 4 ppm of chlorine is safe in drinking water [4, 5].

The adverse health effects of these unsafe levels can be dire. When ingested, lead gradually accumulates in the body and may be carried throughout the bloodstream to the brain. Depending on lead levels, health risks include serious damage to the brain, nervous system, kidneys, red blood cells, and irreversible complication with child development [6]. Lead levels in water can be harmful to all people but are most dangerous to children and pregnant women because they will see negative effects at smaller lead levels than adults [7]. High chlorine levels can cause eye and nose irritation as well as stomach discomfort [8]. Unsafe pH levels can directly harm an individual's health in large quantities. However, a more common risk is that very low pH levels increase the corrosivity of the water source. As corrosive water runs through older pipes, heavy metals like lead and copper can leach into the water supply, leading to serious health complications [9].

In Boston, water is treated at the John J. Carroll Water Treatment Plant. Water undergoes a series of chemical and mechanical filtration processes to remove dangerous compounds. UV light treatment, ozone injection, and other compounds aim to disinfect the water and eliminate dangerous pathogens and algae. Sodium carbonate and carbon dioxide are added to increase the alkalinity of the water and set a balanced pH level [10]. The combination of these processes produces drinkable water that is non-corrosive to pipes and safe for ingestion.

Since all processed drinking water must travel through a network of pipes of varying ages to reach each residence hall, it is possible for other contaminants to reach the drinking water supply. Additionally, if the water has a low pH, the corrosivity can leach heavy metals from local pipes into the water supply. With these possibilities in mind, this study would examine the levels of pH, chlorine, and lead in the unfiltered water from various residence halls across campus to verify that the water treatment is effective and safe for the general Boston population.

6 Procedure

This project utilized three sensors were used to test the quality of the water in terms of chlorine, pH, and lead. The chlorine sensor, the ExStik Waterproof Chlorine Meter shown in Figure 1 below, has a resolution of 0.01ppm and an accuracy of +/- 0.01 ppm [11]. The pH sensor, the Thermo Fisher Scientific EcoTestr pH 1 shown in Figure 2 below, has a resolution of 0.1 pH and an accuracy of +/- 0.1 pH [12]. The lead sensor, the eXact Lead Quick shown in Figure 3 below, has a resolution of 1 µg/L and an accuracy of 3 µg/L [13].

Figures 1&2: Chlorine and pH Sensors

Figure 3: Lead Testing Kit

In order to create a wider database of information from around campus, water samples were tested from six different locations, as well as a control with a Brita filter [14]. These locations included are listed as follows:

- West Village A North
- West Village E
- 319 Huntington Ave
- 407 Huntington Ave
- 136 Hemenway
- Lightview
- Brita Filter (using Lightview tap water)

At each location the steps were followed as similarly as possible to reduce outside interference. Before collecting the samples, the tap was run for at least ten seconds to clear out anything that might have settled in the pipes, and it was kept closer to room temperature. Having it very hot could increase particulates from the pipes, and high temperature variation would affect the dissolution of the chlorine tablets. For each location there were five trials run on the water per quality being tested. The Brita filter used, Atlantis Model No. OB32/OB03, claims a minimum reduction in the chlorine levels of 94%, and 96% for lead levels, but there was no information on how it affected pH [14].

Some of the tests required the use of solutions that were qualified as irritants to the skin and eyes, so whenever these were handled tissues or gloves were used. The whole procedure was performed on either the counter or clear floor to reduce the chance of anything being knocked over.

For the chlorine testing, 20 mL of water were placed in the provided cup with a dissolvable tablet, and they were thoroughly shaken. The sensor was then turned on and placed into the sample, but the results were not recorded until the value settled two minutes later, when the sensor alerted the user. Due to the low number of chlorine tablets in the chlorine testing kit, only one water sample was taken, and it was tested several times. The sensor was reset in between each of the five tests. An example of one of the trials, when testing the Brita filter water, is shown below in Figure 4.

Figure 4: Chlorine Testing

For the pH testing, there wasn't a provided container, so cleaned mugs were used to collect the water samples, with enough water to fully submerge the sensor. Just like with the chlorine sensor, the value needed to settle for about a minute before it stopped drastically changing. Since there were no additives for this testing, the water samples were emptied and taken again for each individual test, and the sensor itself was also reset. One of the trials for the pH sensor of the Brita filter run is shown below in Figure 5.

Figure 5: pH Testing

For the lead tests, 50 mL of water was collected in the provided container and mixed with three drops of ACID-1 Reagent, Part No. 486999, before sitting for at least five minutes. At this point, the meter was turned on and set to the PB2 mode, before being filled and emptied with the prepared mixture four times. When it was filled for the fifth time, five drops of eXact Reagent Pb-2, Part No. 488375-B, were added. Then an eXact Strip Pb-3, Part No. 486997 was placed into the cell at the same time 'READ' was pressed and swished gently back and forth for 20 seconds. The cell was left alone until the counter ran from 1 to 60, before displaying 0 µg and an eXact Strip Pb-4, Part No. 486995 was dipped into the cell and swished around for an additional 20 seconds. Finally, the mixture was left alone for 60 seconds before displaying its final reading. At all tested locations, the sensor consistently output "Lo". The test was run several times to ensure it wasn't just human error, but since the reading was consistently "Lo," it was assumed that the "sample value was below measurement range," as stated in the manual. As a result, the lead testing was only run for the first three locations before realizing that the data could not be analyzed further. The minimum reading for this device was 15 ppb, which indicates that the lead levels from unfiltered water at these residence halls were all below 15 ppb.

7 Results

The data for chlorine tests from each selected location are summarized in Table 1 below. Similarly, the pH measurements from each site as well as their computed averages are summarized in Table 2. A series of five trials were conducted at each site and the average and standard deviation of the five tests was computed and summarized in Table 3.

Table 1: Chlorine Trials at Each Site

	West Village A	West Village E	136 Hemenway	Lightview	407 Huntington	319 Huntington	Brita Filter
Trial 1	1.76	2.17	1.59	1.79	3.54	2.16	0.28
Trial 2	1.73	2.31	1.67	1.75	4.36	2.18	0.31
Trial 3	1.78	2.00	1.68	1.72	3.40	2.09	0.30
Trial 4	1.75	2.31	1.71	1.73	4.10	2.16	0.30
Trial 5	1.83	2.2	1.54	1.77	3.72	2.18	0.29
Average	1.77	2.198	1.638	1.752	3.824	2.154	0.296

Table 2: pH Trials for Each Site

	West Village A	West Village E	136 Hemenway	Lightview	407 Huntington	319 Huntington	Brita Filter
Trial 1	9.7	10.3	10.2	10.0	10.1	10.2	8.7
Trial 2	9.7	10.2	9.9	9.9	10.3	10.1	8.3
Trial 3	9.7	10..3	9.8	9.5	10.2	10.1	8.0
Trial 4	9.7	10.2	10.0	9.7	10.5	10.0	8.0
Trial 5	9.6	10.1	9.9	10.0	10.6	10.1	7.9
Average	9.68	10.22	9.96	9.82	10.34	10.1	8.18

Table 3: Averages and Standard Deviation for Chlorine and pH Trials for Each Site

	Average Chlorine (ppm)	Average pH	STDEV Chlorine (ppm)	STDEV pH
718 West E	2.198	10.22	0.128	0.0837
136 Hemenway	1.638	9.96	0.0705	0.152
Lightview	1.752	9.82	0.0286	0.217
Lightview Brita	0.296	8.18	0.0114	0.327
407 Huntington	3.824	10.34	0.398	0.207
319 Huntington	2.154	10.1	0.0371	0.0707
West Village A North	1.77	9.68	0.0381	0.0447

The averages were calculated for each location for both the chlorine and pH by summing all of the trials at each location and then dividing by the number of trials.

It should be noted that it was not possible to gather numerical data from the lead sensor. The lead sensor has a lower bound of 15 ppb and would report “Lo” for values smaller than this threshold. For each of the sites tested, the sensor consistently reported “Lo”, indicating that the lead levels were below 15 ppb. As this result was a not a numerical measurement, data analysis could not be conducted for the lead levels of the water supplies and no conclusions could be drawn besides that lead levels of unfiltered water samples at each of the selected sites was below 15 ppb.

Next, t-tests were conducted interrogating if there were statistically significant differences between the filtered and unfiltered samples for both the pH and chlorine readings at Lightview. These were done by plugging in the averages of the filtered and unfiltered samples as well as the respective standard deviations into a 95% confidence interval, two-tailed, 2-sample t-test in a TI-nspire CX CAS calculator. The process was used for both the chlorine and pH data. The data be found in table 4.

Table 4: T-tests Between the Brita Filter and the Tap Water for Chlorine and pH

	T-test for difference between Brita filter and tap CHLORINE:	T-test for difference between Brita filter and tap pH:
t actual:	105.75	9.34
p-value:	6.296 e-10	3.491 e-5
Level of Significance	0.05	0.05
Degrees of Freedom:	5.24	6.95

In Table 4, the p-value indicates the probability that the t value is below the t critical. If the p-value is greater than the level of significance, then the t actual is not statistically significant. However, in both cases, the p-value was below the level of significance, and therefore this indicates a statistically significant difference between the two samples. Overall, there was a statistically significant difference between the Brita filter chlorine and pH values compared to those of the unfiltered water samples at Lightview. These t-tests were only conducted between the filtered and unfiltered sources at Lightview due to extraneous variables involved with changing location, such as local particulates from the pipe and variation between water supply of each building.

For the ANOVA calculations, the same process was used with the same calculator, only this time with an ANOVA test function using all the location data except for the Brita filtered data. The number of trials also needed to be plugged in for each location within the ANOVA function. Each location’s respective average, standard deviation, and number of trials was plugged into an array, not including the Brita data in which the ANOVA function of the calculator generated statistical data. The process was repeated for both the chlorine data and pH data. The results can be found in Table 5.

Table 5: ANOVA Tests Between Each Site Excluding the Brita for Chlorine and pH

	ANOVA Results for CHLORINE (not including Brita):	ANOVA Results for pH (not including Brita):
F:	109.2	14.55
P-Value:	1.06 e-15	1.336 e-6
Degrees of Freedom:	5	5
Sum of Squares:	16.69	1.54
Mean Square:	3.338	0.308
Degrees of Agree Error:	24	24
Sum of Squares Error:	0.7336	0.5082
Mean Squares Error:	0.03057	0.02117
sp	0.1748	0.1455

The average chlorine values as explored in Table 1 and Table 3 above are summarized graphically in Figure 6 below. Note that the governmental recommendation of 4 ppm maximum is highlighted in red.

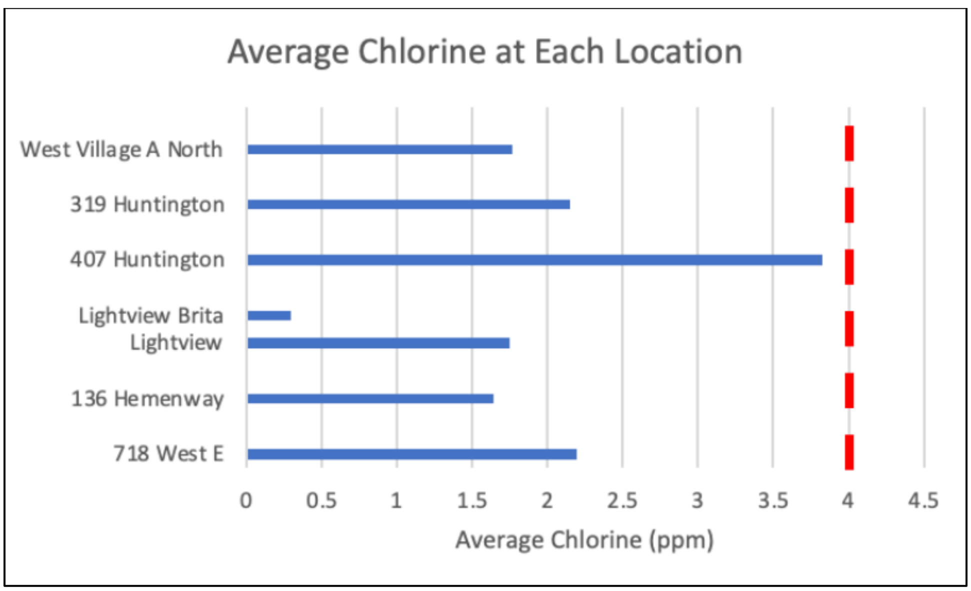

Figure 6: Bar Chart of Average Chlorine at each location

Figure 7 summarizes the average values for pH levels from each location. The EPA recommended range of 6.5 to 8.5 is again highlighted in red to allow for ease of comparison.

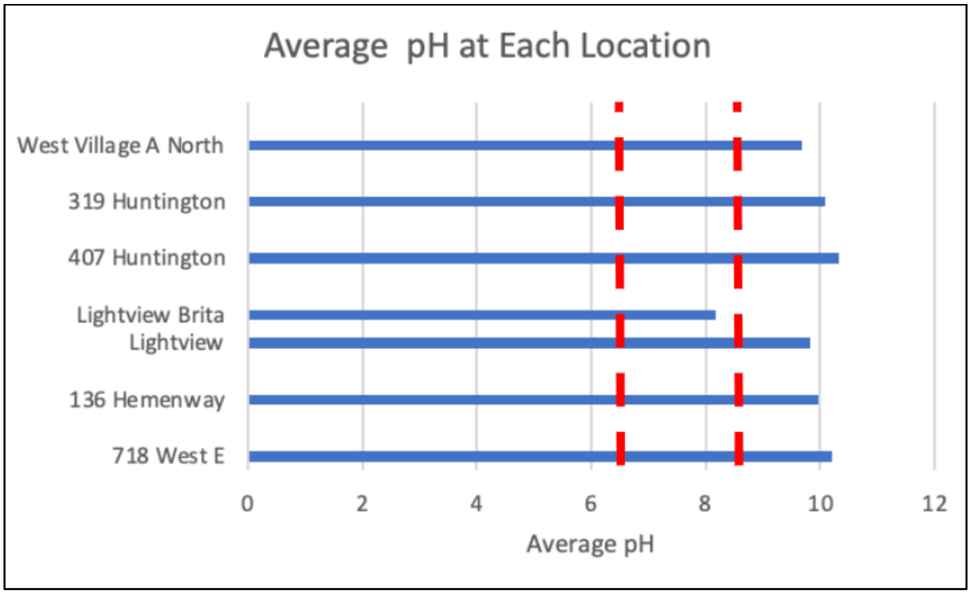

Figure 7: Bar Chart of Average pH at each location

Finally, the average pH and average chlorine at unfiltered locations were graphed to determine whether or not there was a correlation between chlorine and pH at each location. From Figure 8, it can be shown that there is minimum correlation between the chlorine and pH because the trendline is horizontal. In other words, the chlorine and pH content of a water sample are independent. This aligns with expected results because liquid chlorine should not affect pH.

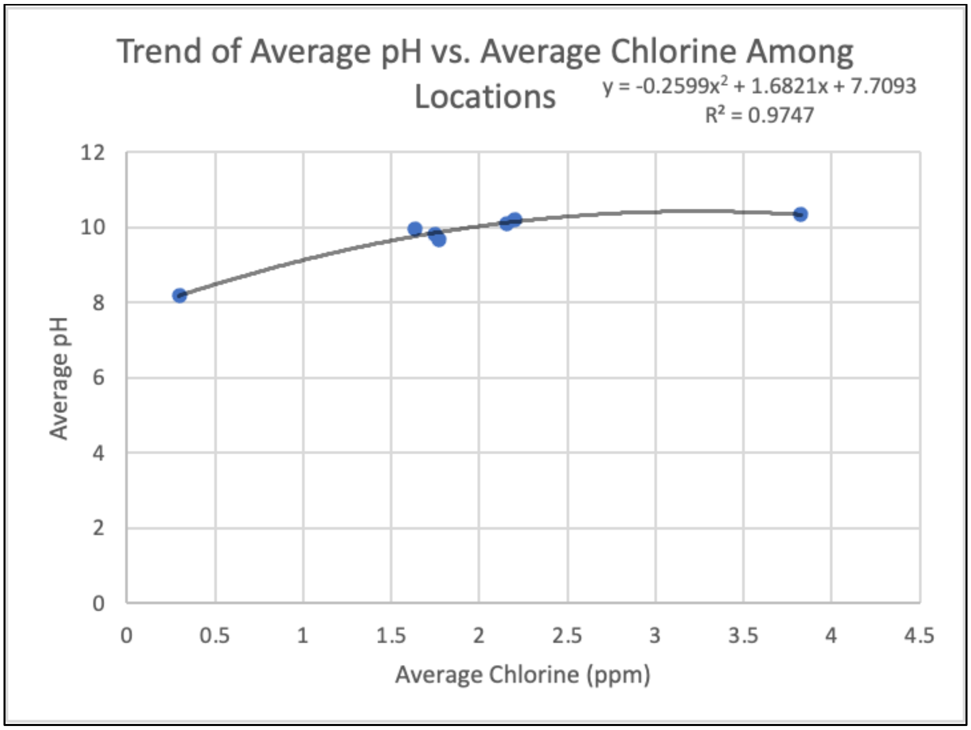

Figure 8: Trend between Chlorine and pH

8 Discussion

Initially, the results for the pH were concerning and it was thought that the sensor was not calibrated correctly. After further research, it was found that Boston purposely keeps the water alkaline as a preventative measure to make sure the water is not acidic. This is because acidic water can leach metals into the water. After knowing this, and rechecking the calibration on the pH meter, these data no longer attracted concern.

The design stage uncertainty from the pH and chlorine sensors was calculated using Equation 1:

$$u_d = \sqrt{u_0^2 + u_c^2} \qquad \text{(Eq. 1)}$$

Where u_d is the design stage uncertainty, u_0 is the interpolation error from device resolution, and u_c is the instrument error from the device accuracy. The interpolation error was found by taking half of the device resolution as specified on its respective spec sheet. The instrument error was taken from the device accuracy. For the chlorine sensor, there were two stated accuracy values, 10% RDG and 0.01 ppm. The 10% RDG was the larger of the two for the range of values gathered, and so this was the accuracy value used to calculate the design stage uncertainty. The resolution, accuracy, and computed design stage uncertainty values are summarized in Table 6 below.

Table 6: Device Characteristics and Design Stage Uncertainty

Thermo Fisher Scientific EcoTestr pH 1	
Resolution (pH)	0.1
Accuracy (pH)	0.1
Design Stage Uncertainty (pH)	0.1118
ExStik Waterproof Chlorine Sensor	
Resolution (ppm)	0.01
Accuracy (ppm)	10% RD: 0.2198
Design Stage Uncertainty (ppm)	0.21986

From this uncertainty analysis, it appears that the gathered data is not greatly affected by uncertainty and that the main conclusions about the overall water supply would hold true.

Before gathering the data, it was important to verify that sample sizes were large enough to avoid statistical error. Based on some preliminary data, it was possible to estimate how many data points should be collected for each variable, chlorine and pH, to avoid major errors. It was possible to estimate the number of data points needed for the preliminary chlorine data using Equation 2:

$$t_{v,p}S_{x'} = (0.01)x \qquad \text{(Eq. 2)}$$

In this equation, $t_{v,p}$ is the t-value for a given degrees of freedom and confidence level. $S_{x'}$ is the standard deviation, and x is the mean. The value 0.01 was determined based upon a desired error of +/- 1% at 95% confidence level. Assuming future data sets will have a similar mean, the standard deviation could be calculated. This value could then be used to determine the number of values required to achieve this level of error in the confidence interval, as shown in Equation 3:

$$S_{x'} = \frac{S_x}{\sqrt{N}} \qquad \text{(Eq. 3)}$$

Using this process for the preliminary chlorine data, the minimum number of chlorine data points to be within +/- 1% at a 95% confidence level was 21 data points. For the pH data, 38 data points should have been collected.

In total, 35 data points were gathered for each variable. This data quantity is within the goal for chlorine, but slightly below the range for pH. Therefore, the conclusions drawn from the pH data should be verified from further experimentation.

Based upon the t-test analyses discussed in Table 4, it can be concluded that the Brita filter has statistically significant effects upon the pH and chlorine levels compared to unfiltered samples at Lightview. The ANOVA test explored in Table 5 revealed that there were statistically significant differences in chlorine and pH across each location, indicating that there are additional local variables at each building that affect their water quality. Based upon the averages at each location and the governmental guidelines of 6.5 to 8.5 pH, it can be concluded that each location was above the recommended pH range. All locations were below the recommended maximum of 4 ppm of chlorine. However, it should be noted that 407 Huntington had higher chlorine levels than the other locations. Measurement device uncertainty should not affect the conclusions drawn by this examination.

9 Conclusions

For chlorine levels, it was determined that the chlorine levels at every site tested were below the CDC guidelines of 4 ppm. For the pH study, the unfiltered samples from each residence hall had an average pH above 8.5, exceeding the EPA guidelines of 6.5 to 8.5. However, further research revealed that this is not a major health concern and should be expected, as Boston water is intentionally more alkaline to prevent the leeching of heavy metals into the water supply. Only the sample filtered with the Brita filter had a pH within the EPA guidelines, with a reading of 0.296 ppm. For the lead tests, all tested locations indicated a reading of “Lo”, preventing further data analysis and indicating that these locations had lead levels below 15 ppb. Overall, these findings indicate that the unfiltered tap water is within safe levels of lead and chlorine, and slightly exceeds recommended guidelines of pH, but not enough to endanger health.

Statistical analyses in the form of t-tests revealed that the sample filtered with the Brita filter was statistically significantly difference compared to the unfiltered samples in the same building. This finding indicates that the Brita filter does make a statistically significant difference in improving the quality of the water with respect to pH and chlorine levels. An ANOVA test revealed that there were statistically significant differences across each of the locations tested. This finding suggests that local variables at each building had a statistically significant effect upon the pH and chlorine levels in the water supply. A correlation test between pH and chlorine revealed that there is no correlation between pH levels and chlorine levels, matching theoretical predictions.

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