COMPARING THE WATER QUALITY OF STREAMS FEEDING A WATERSHED

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The Ala Wai Canal is one of the main waterways and watersheds on the island of O‘ahu, but it does not meet EPA water quality standards. Despite being deemed unsafe, during paddling season a number of adult and teenage paddling crews practice in the Ala Wai for a variety of reasons. In recent years, more discussion and focus has been turned to improving the water quality of the Ala Wai Canal. By doing a water quality study on two tributaries that feed into the Ala Wai watershed, the research group hoped to determine if there was a statistically significant difference between the mean water quality of the two streams. By measuring 952 samples in Pūkele Stream and 889 samples in Makiki Stream taken every fortnight over a 14-year period, the representative suspended solids entering from the eastern and western sides of Ala Wai Canal are compared statistically. Thus, a good general picture of the average difference in water quality between the tributaries is obtained. Through this sample study, it was found that there is a statistically significant difference between the average water quality of the two streams. This finding implies that there is a big enough difference between the suspended solids in the two streams to prioritize the Pūkele Stream over Makiki Stream for remedial actions.

Keywords: Ala Wai Canal, Suspended sediment, Water treatment, Z-test, Confidence.

1 INTRODUCTION

Suspended solids pollute tributaries in the form of organic materials, bacteria, soil, debris, etc., and are regularly filtered and measured to ensure proper water quality to protect the environment. In Honolulu, Hawai‘i, three major tributaries, the Mānoa, Pālolo and Makiki streams, all merge to drain into the Ala Wai Canal, located in the hustling resident and business area of Waikīkī. The accumulation of sediments and suspended solids from stormwater runoff have impaired the Ala Wai Canal by not meeting the Environmental Protection Agency’s (EPA) water quality standards (EPA 2009). This greatly influences the purpose of the canal as a drain for stormwater runoff and recreational use by paddlers and sea-goers. The Makiki and Pūkele streams are used by hikers, students conducting activities, fishers and more. Therefore, the health and cleanliness of the streams must be enforced. By sampling and determining the difference in water quality of these two similar streams, the extent of damage in the streams can be analyzed and their connection to the major waterway, the Ala Wai Canal and surrounding stream systems can be considered in water treatment.
1.1 Background

Suspended sediments in water are fine solids that may be present in any given sample. Suspended solids affect water quality by increasing turbidity and contaminating water for daily usage. Suspended sediment can come from soil, organic matter, particle discharge, and more. The presence of solids in water can indicate a water source’s clarity and safety. Water that contains a high number of suspended solids are more likely to pose health risks from pathogens and chemicals. Streams such as the Makiki and Pūkele streams contribute to the pollution of suspended solids in the Ala Wai canal, further increasing health risks to people and wildlife. The tributary network that comprises the Ala Wai watershed is depicted in Figure 1 below (Esri 2012).

![Figure 1. Water tributaries of the Ala Wai Watershed Complex (Modified from Esri 2012).](image)

The Makiki and Pūkele Streams coincide with hiking trails, wildlife and even businesses as they make their way to the Ala Wai Canal. The Makiki and Pūkele streams are major stream networks in Honolulu, Hawai‘i that experience human traffic, animal waste, and organic matter, all contributing to the increase in suspended solids traveling to the Ala Wai Canal and surrounding oceans.

The Ala Wai Canal is a large watershed surrounded by busy urban life from the campus of the University of Hawai‘i at Mānoa to the hotels in Waikīkī. Sediment in the Ala Wai can alter ecosystems and abundant wildlife as these particles travel to the surrounding ocean. Sampling of suspended solids and the study of their impacts is a relatively new practice, and efforts to mitigate the discharge of sediments into the rivers and improve the Ala Wai Canal are limited (Taniguchi 2020). The collected data of suspended sediment in the Pūkele and Makiki Streams in mg/L were taken by the United States Geological Survey (USGS) from 2010 to 2023 (USGS 16244000) (USGS 2023b). Many factors contribute to the efficiency of collecting these samples including elevated levels of human traffic, debris, trash pollution, fencing, plant species and more.
1.2 Purpose

It is important to understand which streams are contributing to the pollution in the Ala Wai Canal. Doing this study of two streams helps to determine if it is worth the financial investment to assess different branches of streams draining to the Ala Wai. The Ala Wai replaced major wetlands that previously filtered sediment and trash that came down by streams in Makiki, Mānoa and Pālolo (Taniguchi 2020). Due to this large geographic change and the resulting reduced filtration, sediment could be building up in these valleys, impacting wildlife and other factors that rely on these water sources. By identifying the levels of suspended sediment in these streams through sampling, we can make decisions on water treatment for these stream networks and the Ala Wai waterway.

1.3 Objective

In evaluating the difference in means between samples of suspended solids in the Makiki and Pūkele streams, their contribution to the pollution of the Ala Wai Canal in their drainage path will be better understood for future water treatment processes. The two streams are suspected to have different amounts of suspended solids and different contributions of pollution due to their proximity to the Ala Wai.

1.3.1 Hypothesis

As the Makiki Stream is closer to the mouth and the Pūkele Stream is closer to the head of their respective streams, it was hypothesized that their mean suspended sediment values would have a statistically significant difference at 95% confidence.

2 DATA COLLECTION METHODOLOGY

Data was collected via the National Water Information System (NWIS): Web Interface (USGS 16238000), a publicly available data repository maintained by the United States Geological Survey (USGS) (2023b). The suspended sediment concentration data was collected between January 2010 to April 2023, roughly once a fortnight and sampled three times each collection day (Figure 2).

![Figure 2. USGS map of surveyed sites on Oahu, emphasis on the Ala Wai Watershed Complex (Modified from USGS 2023a).](image-url)
A map published on the site depicting current sampling locations was utilized to determine the streams surveyed within the area of interest for this study, the Ala Wai Watershed Complex. Of the over sixty sites being sampled on the island of O‘ahu, only eight were sites that contributed to the Ala Wai Watershed (See Figure 2 within the blue rectangle). Of those eight sites, one was for Pūkele Stream and one for Makiki Stream. The Pūkele Stream represents streams that feed into the Eastern side of the Ala Wai Canal, while the Makiki stream represents the streams that feed into the western side.

Once the streams of interest were selected, all available data points were collected from their respective USGS data sites (USGS 2023b). This amounted to 952 data points for Pūkele Stream and 889 data points for Makiki stream. These 1,841 data points became the basis of this study.

3 ANALYSIS AND RESULTS

3.1 Determining Level of Significance (α) and the Confidence of Statistical Difference

To determine whether there is a statistically significant difference between the average suspended sediment values of the Makiki and Pūkele Streams, hypothesis testing of the difference of means was employed. The following statements were set as the hypothesis and alternative, with alpha to be experimentally determined.

\[ \text{Hypothesis: } \mu_1 - \mu_2 = 0; \text{ Alternative: } \mu_1 - \mu_2 \neq 0 \] (1)

To test the hypothesis statement in Eq. (1) above, the calculated \( Z_{\text{stat}} \) value is generally compared to the upper and lower bounds of the confidence interval of \( Z_{\alpha/2} \) to see if it is within the expected margin of error. If \(-Z_{\alpha/2} \leq Z_{\text{stat}} \leq Z_{\alpha/2}\) then there is determined to not be a statistically significant difference. To calculate \( Z_{\text{stat}} \) for the difference between means, the normative formula in Eq. (2) was used:

\[ Z_{\text{stat}} = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \] (2)

where \( \bar{x}_1, n_1, \) and \( s_1 \) are the mean of suspended sediments in mg/L, sample size, and sample standard deviation for Pūkele Stream; and \( \bar{x}_2, n_2, \) and \( s_2 \) are the mean, sample size, and sample standard deviation for Makiki Stream. A sample size of 952 (\( n_1 \)) and 889 (\( n_2 \)) was taken for the two streams. Consequently, \( \bar{x}_1 \) and \( \bar{x}_2 \) were found to be 815 mg/L and 578 mg/L. Finally, the sample standard deviation, \( s_1 \) and \( s_2 \), were calculated as 1,537 mg/L and 905 mg/L. Taking the above calculated values and plugging back into the \( Z_{\text{stat}} \) formula for the difference of means, \( Z_{\text{stat}} \) was found to be 4.05. The \( Z_{\text{stat}} \) value compared to the normal distribution can be seen in Figure 3 below.

![Figure 3. Normal distribution of the difference between means with calculated \( Z_{\text{stat}} \).](image-url)
To calculate the cut-off point for the value of $\alpha$ that accepts or rejects the hypothesis, $Z_{\alpha/2}$ must be set equal to $Z_{\text{stat}}$. Given $Z_{\text{stat}}=Z_{\alpha/2}$, the corresponding alpha can then be calculated using standard tables. This yields an experimentally determined value for $\alpha/2$ of $0.01\%$ (or $p$-value = 0.0001), implying 99.99% confidence. But a $p$-value of 0.0001 is extremely small, indicating that it is extremely unlikely that $\bar{x}_1$ can be equal to $\bar{x}_2$.

3.2 Statistical Descriptions of Distribution and Variance for Each Grouped Data Stream

To begin analyzing the data in groups, class widths for each data stream need to be determined. For the Makiki Stream, a range of 1.0 to 9,530 mg/L for suspended sediment data values was split evenly into ten groups, accommodating all the data, and giving a class width of 1,000 mg/L. Tallying the frequency of data in each range resulted in the frequency distribution of Figure 4.

![Figure 4. Frequency distribution of the grouped data for Makiki Stream.](image)

Based on the range of the suspended sediment data values from Pūkele Stream, roughly 1.0 to 21,000 mg/L, ten groups of equal width of 1,000 mg/L were made, where 99.5% of the data fit within this, which is practically alright. This gives the frequency distribution shown in Figure 5.

![Figure 5. Frequency distribution of the grouped data for Pūkele Stream.](image)

These frequency distribution charts depict a simplified visual for the spread of the data collected for each stream. Though the distributions here are exponential, the normal distribution is very robust for handling all types of curves, especially when the sample size is large (Skovlund and Fenstad 2001). From this distribution, one can further examine the variance of the grouped sample utilizing the standard deviation formula for grouped data. Using the previously determined values
for each stream, the standard deviation of the grouped sample for each stream was found to be 1,384 for Pūkele Stream and 841 for the Makiki Stream, representing the standard deviation after smoothing the fluctuation.

4 OBSERVATIONS

The Pūkele Stream’s suspended sediment concentration from the full set of data collected ranged from 20,100 mg/L to 1.0 mg/L; while the full range of the Makiki Stream’s suspended sediment was 9,530 mg/L to 1.0 mg/L.

The higher concentrations of suspended sediment could be influenced by some error or outside factors such as trash dumping, animal waste, rain, and more. For example, the maximum concentration of 20,100 mg/L from the Pūkele Stream is calculated to be 12.5 standard deviations above the mean of 815 mg/L, which would make the probability of obtaining that number nearly 0%. Likewise, the maximum concentration of 9,530 mg/L in the Makiki Stream equates to 9.89 standard deviations above the mean of 578 mg/L, which would also result in a nearly 0% chance that the value would be found.

5 CONCLUSIONS AND IMPLICATIONS

The calculations from this study show that there is a significant difference between the average suspended sediment in the Pūkele Stream when compared to the Makiki Stream because the $z_{stat}$ value of 4.05 falls outside of any confidence interval that is less than 99.99%. In other words, the difference between means will not be significant if $z_{a/2}$ is greater than 4.05.

The presence of significant difference between the two streams at an exceptionally high confidence lends itself to the conclusion beyond a reasonable doubt that each stream contributes varied amounts of suspended sediment to the Ala Wai Canal.

Having discovered the difference in the pollution levels by suspended solids between the two streams, over a period of measurement of 14 years, it is observed that the difference is systemic and not by chance. Hence, the pollution in the Pūkele Stream, which feeds the eastern side of the Ala Wai Canal is fundamentally more severe than the pollution that feeds the western side of the canal through the Makiki Stream. As such, the Ala Wai Canal can be expected to be more polluted than if it was the other way around, since the only opening of the canal to the ocean is on its western end. High pollution levels restrict leisure activities such as canoeing and kayaking. Also, the Pūkele Stream must be prioritized over Makiki Stream for any pollution mitigation activities.

References


