Linking Water Temperature Variability to Water Quality Dynamics in Beck Lake, an Urban Inland Lake in Chicago (2020–2024)

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Abstract

This study examines the effect of climate variability on water quality in Beck Lake, an inland urban lake in Chicago, Illinois, from 2020 to 2024. The lake is maintained by the Chicago Park District and contains aquatic life such as Bluegill, Largemouth Bass, and Northern Pike. To determine climate influence, satellite-derived water temperature data were analyzed using time series segmentation and non-parametric trend analysis in Python. Specifically, temperature trends were tested using Kendall's τ ($\tau = -0.0188$, $p = 0.597$), and correlations between water temperature and NDCI, TP, and EC were positive and statistically significant ($r = 0.356$, 0.166, and 0.329 respectively). Breakpoints representing statistically significant changes in water temperature were calculated, and corresponding trends in water quality metrics during these segments were examined. Water quality indicators, including the Normalized Difference Chlorophyll Index (NDCI), Normalized Difference Turbidity Index (NDTI), total phosphorus (TP), and electrical conductivity (EC), were extracted from Sentinel-2 imagery using Google Earth Engine. Temporal patterns in these metrics were analyzed in Python using non-parametric methods to find their response to water temperature shifts. Specifically, The results show chlorophyll and phosphorus were positively correlated with temperature, suggesting increased biological activity and nutrient loading. During warmer phases, change in turbidity and conductivity were also observed, indicating possible changes in physical and chemical processes within the lake. These results show strong seasonal co-variation between water temperature and water quality parameters. Based on these water quality shifts, fish species like Bluegill, Largemouth Bass, and Northern Pike that are commonly found in the lake may face periodic stress from lower oxygen levels, algal blooms, and reduced water clarity during warmer, nutrient-rich periods. These conditions can affect their feeding, spawning, and overall habitat

suitability. This study demonstrates the value of integrating Earth observation data with climate-sensitive indicators and non-parametric analytics to improve understanding of how urban aquatic ecosystems and life respond to climate variability.

Introduction

Motivation for Research

Urban inland lakes are blooming ecosystems for aquatic life, plant growth, and bacterial growth. They have massive implications for the environment, but also public health. Beck Lake, the chosen lake for this study, is a popular lake for human activity. Recreational activities such as fishing, boating, and picnics are frequent, which means that maintaining water quality is extremely important to ensure disease prevention and human health. In recent years, rising air temperatures and extreme rain events have added bacteria and worse water quality conditions in lakes worldwide (Collingsworth et al., 2017). It is important to note that while global lakes are warming slower than surface air temperature due to accelerated evaporation, water temperature for lakes is still continually rising (Global Aqua Remote Sensing Laboratory, 2023). Understanding how climate variability influences water quality is crucial for maintaining ecological health, public health, and sustainability.

Furthermore, like the majority of urban lakes, Beck Lake is vulnerable to water quality driven stressors such as nutrient loading, algal blooms, and rising water temperatures. These stressors can lead to habitat compression, hurt spawning rate, and put overall stress on fish population (Brooks et al.,2025). Further research has shown that warming trends can significantly hurt fish survival rates (Ivanova et al.,2024), and oxygen depletion can significantly alter fish habitat, and growth (Tang et al., 2020). By studying how a climate driven parameter, water temperature correlates with water quality parameters, we can effectively identify trends and correlations to have a better idea of the environmental stressors in the lake. We can then apply previous research on fish to determine periods of stress or habitat loss to potentially help sustainability and aquatic life. The aforementioned water quality parameters used in this study are the following: Normalized Difference Chlorophyll Index (NDCI), the Normalized Difference Turbidity Index (NDTI), total phosphorus (TP), and electrical conductivity (EC). We hypothesized that water temperature will exhibit both seasonal and long-term variability that significantly affects NDCI, and TP concentrations, potentially driving algal blooms and nutrient loading in Beck Lake.

Figure 1: A google maps satellite image of Beck Lake

Methodology

Remote Sensing Satellite Technology

In order to collect the water temperature and water quality data for Beck Lake, we used remote sensing satellite technology. Satellite sensors like Landsat and Sentinel provide multi-band spectral data ranging from 2020-2024 –Sentinel-2 data (10–20 m resolution, 5-day revisit) and Landsat-8 data (30 m resolution, 16-day revisit) were processed in Google Earth Engine to derive each index–enabling the use of index-based techniques such as Surface Water Temperature and various water quality parameters (see Figure 1 and 2 for index-based techniques). These parameters are: Normalized Difference Chlorophyll Index (NDCI), NDCI is used to estimate chlorophyll-a concentration in water, helping to detect algal blooms and assess eutrophication levels; Normalized Difference Turbidity Index (NDTI), NDTI is used to measure water turbidity, indicating sediment concentration and water clarity; Total Phosphorus (TP), TP is an essential water quality parameter that contributes to eutrophication and algal blooms. It can be estimated using reflectance-based indices; Electrical Conductivity (EC), Conductivity measures how well water can pass an electrical current; Elevated EC in lakes suggests that pollutants have entered the water body, specifically inorganic, charged particles. All variables were expressed in consistent units: temperature (°C), EC (µS/cm), and TP (mg/L).

$$NDCI = \frac{B5 - B4}{B5 + B4}$$

$$NDTI = \frac{B4 - B3}{B4 + B3}$$

$$TP = \frac{B4 + B8}{2}$$

$$EC = -18.66 + 124.07 \cdot \left(\frac{B3}{B2}\right)$$

Figure 1: Formulas used to calculate NDCI, NDTI, TP and EC.

	Sentinel-2A MSI			Landsat 8 OLI		
Band	Spectral region	Wavelength range (nm)	Resolution (m)	Spectral region	Wavelength range (nm)	Resolution (m)
B1				Blue	435–451	30
B2	Blue	458–523	10	Blue	452–512	30
B3	Green peak	543–578	10	Green	533–590	30
B4	Red	650–680	10	Red	636–673	30
B5	Red edge	698–713	20	NIR	851–879	30
B6	Red edge	733–748	20	SWIR1	1566–1651	30
B7	Red edge	773–793	20	SWIR2	2107–2294	30
B8	NIR	785–899	10			
B8A	NIR narrow	855–875	20			
B11	SWIR	1565–1655	20			
B12	SWIR	2100–2280	20			

Figure 2: Sentinel-2A and Landsat 8 Bands and Spectral Regions

Breakpoint Detection and Trend Analysis

First, we created a time series plot with 5 subplots representing water temperature and the 4 water quality parameters. We used statistical libraries ruptures, pymankendall, and kendalltau in order to analyze the data. These libraries use two primary statistical approaches: PELT(Pruned Exact Linear Time) for breakpoint detection and the Mann-Kendall test for trend analysis. Temperature regime shifts were detected using the PELT algorithm, using a conservative penalty to identify three to four major season breakpoints. Then, nonparametric trend analysis was performed using the Mann-Kendall test to assess the presence, direction, and significance of trends. Correlation between water temperature and each water quality parameter was measured using both Spearman’s rank correlation and Kendall’s tau. These nonparametric correlations tested monotonic co-variation between ranked values. Statistical significance was assessed at the threshold α = 0.05. All computations were performed in Python 3.11.7. The dataset contained 353 datapoints from 2020-2024.

Results

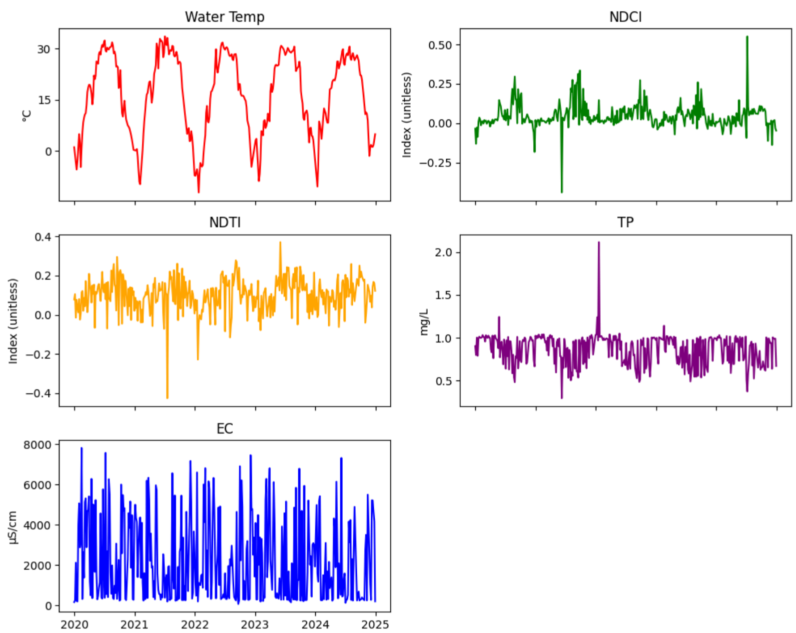

Figure 1: Graphs of Water Temperature, NDCI, NDTI, TP, and EC with on time plot spanning 2020 to 2025.

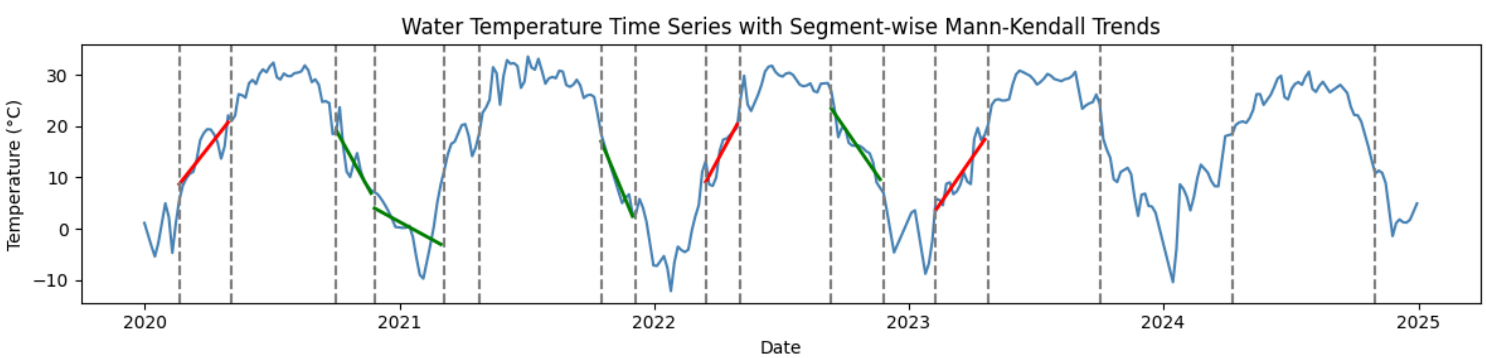

Figure 2: Graph of Water Temperature Time Series Plot with breakpoint and trend analysis.

Variable	Kendall τ vs. Temp	p-value	Spearman r vs Temp	p-value
NDCI	0.356	9.3*10^-12	0.262	6.8*10^-8
NDTI	0.074	0.177	0.028	0.57
TP	0.166	0.001	0.137	0.01
EC	0.329	2*10^-10	0.267	6.8*10^-9

Table 1: Nonparametric trends and temperature correlations, with p-values.

Water Quality and Temperature Trends

Our analysis revealed seasonal patterns in Beck Lake, with higher temperatures during summer months and lower temperatures during winter months. These fluctuations were consistent with regional climate variability, indicating a strong climatic influence on the lake's temperature. Water temperature trends showed a positive correlation with multiple water quality indicators. NDCI, for example, had higher water temperatures associated with elevated NDCI values, suggesting an increased risk of algal blooms during warm periods(Spearman r=0.3561, p < 1*10^-10, Kendall's $\tau = 0.262$, $p < 1\times10^{-7}$) . Similarly, TP (Total Phosphorus linked warmer conditions with elevated phosphorus levels, indicating greater nutrient loading in the water column($r = 0.166$, $p = 0.001$; $\tau = 0.137$, $p = 0.0096$). Conductivity also correlated strongly with temperature($r = 0.329$, $p < 1\times10^{-9}$; $\tau = 0.267$, $p < 1\times10^{-8}$). In general, seasonal warming trends were often matched by nutrient surges and higher conductivity, but not always by proportional increases in NDCI. This suggests that nutrient buildup without immediate algal response can occur.

Discussion

While this study is the first to integrate these specific techniques on an urban lake, our findings about the observed relationship between seasons, water temperature, and water quality are consistent with findings from previous studies. As discussed in the results, these environmental changes have high effects on the fish populations within the lake. These conditions represent stressful habitat scenarios for fish. Warmer, nutrient rich phases likely reduce dissolved oxygen through increased algal respiration, aligning with observed summer stress periods for Bluegill and other shallow-water species. Bluegill experience stress below ~5 mg/L dissolved oxygen. In other times, the effects on the fish varied by the species. For example, from 11/26/2020 to 3/1/2021, the temperature dropped, while NDCI and TP went up, which created a low amount of oxygen in the lake. Therefore, the Bluegill species became more stressed, while the Largemouth Bass was most likely dormant, and the bigger Northern Pike was in stable conditions. These results further demonstrate Beck Lake's sensitivity to climate-driven water quality changes. The statistically significant correlations ($p<0.01$) between temperature and water quality indicators confirm that thermal variability is a reliable indicator of ecological stress. Importantly, this study demonstrates the value of continuous monitoring of small urban lakes. Oftentimes, large lakes are significantly researched, yet smaller lakes like Beck Lake go untouched. However, their limited volume and bigger perimeter to area ratio make the lakes more sensitive to temporal shifts as well as nutrient loading. By integrating remote sensing with statistical trend and breakpoint analysis, we have created the possibility to detect early warning signs of ecological stress. Further research into this topic could contain more urban lakes, create a generative model to predict conditions, or even create targeted management strategies to support the fish in Beck Lake.

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