Water Quality in the Chattahoochee River and the Impacts of a Major Metropolitan Area

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Introduction

Background

Water quality in streams and rivers throughout the world is impacted by a variety of factors, from natural processes and climatic conditions to surrounding land use. In assessing water quality, many studies have focused on dissolved oxygen (DO) levels due to the fact that this water quality parameter has been shown to be strongly correlated with aquatic ecosystem health in stream environments (Bailey and Ahmadi, 2014; Nas and Nas, 2009). Although DO levels can vary regionally, states often establish standard minimum levels. For example, in Georgia, the location of this study, DO state standards state that daily average DO levels should be no lower than 5.0 mg/L and no less than 4.0 mg/L at any time (Ga. Comp. R. and Regs, 391-3-6-.20(11)).

DO levels are positively correlated to many natural processes, including upstream solute concentrations, algal functional processes, stream channel turbulence, and groundwater inputs (Bailey and Ahmadi, 2014). However, despite the natural processes that support higher DO levels, land use is considered to be the strongest factor affecting DO levels and in lowering stream water quality (Gimenez, Lansac-Toha, and Higuti, 2015; Taka, Aalto, and Luoto, 2015; Goonetilleke *et al.*, 2005).

Streams in rural areas are subject to non-point source agricultural pollutants via erosion and runoff (Taka, Aalto, and Luoto, 2015). Urban streams are subject to both point source and non-point source inputs of pollution, such as industrial effluent. As such, studies have found that stream water quality in areas impacted by urban land uses is significantly worse than in rural areas (Gimenez, Lansac-Toha, and Higuti, 2015; Goonetilleke *et al.*, 2005), which has been attributed to the differing land use practices between urban and rural environments (Gimenez, Lansac-Toha, and Higuti, 2015; Frizzera and Alves, 2012).

Urbanization affects stream water quality through several main types of pollution: inputs of organic carbon, inorganic total dissolved solids, and thermal pollution. Organic carbon pollution from urban areas has a significant effect on DO levels due to associated high microbial activity, which removes DO from the water (Goonetilleke *et al.*, 2005). Inputs of inorganic total dissolved solids are also detrimental to stream water quality and enter streams via municipal water discharge and industrial effluents. These inputs lead to low pH values, high conductivity values, and high concentrations of nitrogen and phosphorous (Gimenez, Lansac-Toha, Higuti, 2015), and have been found to lower DO levels (Frizzera and Alves, 2012; Nas and Nas, 2009). Further studies have shown that pH, which is generally lower in urban areas due to acidic industrial atmospheric emissions, is correlated with DO (Taka, Aalto, and Luoto, 2015).

Additionally, urban areas are significant sources of thermal pollution in streams due to the presence of pavement, roofs, and other heat gathering surfaces (Gimenez, Lansac-Toha, and Higuti, 2015). The increased stream water temperature due to thermal pollution from urbanization, as well as the resulting increase in biological activity, has also been shown to lower DO levels (Taka, Aalto, and Luoto, 2015).

Objectives

In this study, we examined two sections of the Chattahoochee River, one upstream and one downstream of metro Atlanta. As Atlanta's population grows, it is likely that urbanization could have increasing impacts on the health of the river. As such, this study is useful because it examines the water quality upstream and downstream of the city to observe any significant differences. We delineated the upstream (before) and downstream (after) sections using U.S. Highway 78, which runs east to west across the Chattahoochee River and just north of downtown Atlanta.

We examined data from 44 samples upstream of metro Atlanta and 40 samples downstream of metro Atlanta and the variables of location, water body type, temperature, DO, pH, conductivity, turbidity, and E. coli, which may influence DO levels as the river passes through metro Atlanta. Thus, the goals of this study were 1) to determine if metro Atlanta has a significant effect on DO levels on the Chattahoochee River, 2) to assess whether the mean DO levels both before and after metro Atlanta were higher than the state standard, and 3) to determine what variable(s) had the largest effect on the difference in DO levels between the section of river upstream of metro Atlanta and downstream of the urban area, as well as the magnitude and direction of these effects.

To accomplish our goals, we performed t-tests to compare the mean DO levels between sites before and after Atlanta. We also used an ANOVA to compare the effect of sampling location and waterbody type (mainstem or tributary) on DO levels. Finally, we conducted a multiple linear regression analysis to determine which variables affect DO levels. We expect to find that mean DO levels are higher upstream of the city and that the mean DO levels both before and after the city will be within the acceptable state standard. In our regression analysis, we expect that all of the explanatory variables will have an impact on DO levels.

Methods

Data Collection

We received the data for this study from the Georgia Adopt-A-Stream program. Georgia Adopt-A-Stream is a citizen science water quality monitoring program facilitated by the Georgia Environmental Protection Division. From June 21-27, 2014, Adopt-A-Stream staff members and certified volunteers canoed more than 110 miles of the Chattahoochee River, starting north of Atlanta and then passing through the city before ending the journey near the Alabama border. Water quality monitors collected data on many different parameters including DO, conductivity, air and water temperature, E. coli bacterial levels, turbidity, geographic coordinates, and sample type (mainstem or tributary).

To analyze water samples for DO concentrations, the monitoring team utilized LaMotte DO Water Test kits to perform a Winkler titration. To collect conductivity data, monitors used Oakton PCS Testr 35 conductivity meters calibrated with a 250 µS/cm calibration solution. For the bacterial data, the monitoring team collected water samples and plated them on 3M™ Petrifilm™ E. coli count plates and incubated the plates for 24 hours at 35°C. Adopt-A-Stream used a Hach 2100Q Turbidimeter to test the samples for turbidity levels. The U.S. EPA and Georgia Adopt-A-Stream partnered to develop a Quality Assurance Project Plan (QAPP) to ensure that the methods volunteers use to collect data would be reproducible and accurate. All of the sampling methodologies described above are in compliance with the QAPP.

Results

Descriptive statistics

Overall, we used 44 sites in the "before" Atlanta group (mean=7.15, median=7.15, range=3.4 to 10.5, std. dev= 1.32) and 40 sites in the "after" Atlanta group (mean=6.61, median=6.75, range=4.3 to 7.7, std. dev.=0.65). The dataset contained some NA values, which we removed from our analysis.

Before we conducted any tests, we checked the normality of the response variable, DO, by plotting a histogram of the data. We found the histogram of the DO data to be normally distributed. Therefore, we did not need to transform the data.

We first used a two-sample, two-way t-test to determine if there was a difference in mean DO levels upstream and downstream of Atlanta. We conducted a Welch's t-test to account for the difference in group variances. The null hypothesis stated that there was no significant difference between the mean DO levels of the two groups, and the alternative hypothesis stated that there was a significant difference between the mean DO levels of the two groups. The results (t = 2.39, df = 63.998, p-value = 0.02) indicated that there is significant difference in mean dissolved oxygen levels between the two groups. A boxplot of the results suggested that mean DO levels were greater before Atlanta than after Atlanta (Figure 1).

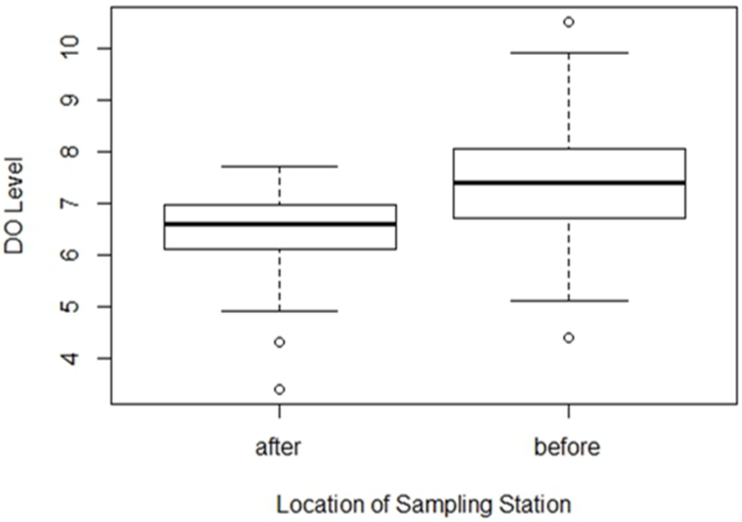

Figure 1 Box plot displaying sample distribution of DO before and after metro Atlanta.

We also conducted a one-sample, one-way t-test to determine if mean DO levels in the Chattahoochee River upstream and downstream of Atlanta were significantly lower than the state standard average of 5 mg/L. Our null hypothesis stated that mean DO levels in both sampling groups were greater than or equal to 5mg/L. The alternative hypothesis stated that mean DO levels in the groups were not greater than or equal to 5 mg/L. The results for the upstream group (t = 10.81, df = 43, p-value = 1) and the downstream group (t = 15.73, df = 39, p-value = 1) were not statistically significant and showed that mean DO levels were consistently greater than the state standard.

Once we determined that DO levels varied upstream and downstream of Atlanta, we attempted to determine if other factors also affected DO levels in the Chattahoochee River. Our null hypothesis stated that sampling location (before and after Atlanta) and waterbody type (tributary or mainstem) did not have a significant effect on mean DO levels. Our alternative hypothesis stated that the explanatory variables did have a significant effect on mean DO levels.

We used an ANOVA to test the effect of these explanatory variables on mean DO levels. Because our data was unbalanced, we used a Type 2 ANOVA. The results showed that only sampling location had a significant effect on DO levels (F=16.178, df=1, p-value< 0.00013). Given the significant effect of location, we rejected the null hypothesis that there was no relationship between DO, waterbody type, and location.

Finally, we used multiple linear regression to analyze the effect of the explanatory variables on DO levels. Our null hypothesis stated that conductivity, E. coli, turbidity, water temperature, pH, and sampling location had no effect on DO levels. Our alternative hypothesis stated that at least one of the explanatory variables had a significant effect on DO levels. Our full model analyzed the effects of all of these factors on DO levels. To select the minimum adequate model, we removed effects that did not show statistical significance. However, we chose to leave location in the model even though it was not statistically significant ($p < 0.15$) because our previous tests demonstrated that location was important in predicted DO levels.

We determined that the model containing turbidity, water temperature, and location predictor variables was the minimum adequate model: (y=9.37 - 0.0286(WaterTemp) - 0.0996(Turbid) + 0.349(factor(Location)), R^2 = 0.3314, $F_{3,81}$ = 13.38 , p = 3.554e-07).

According to the reduced model, for a 1 NTU increase in turbidity, DO decreases by 0.0996 mg/L. For a 1 degree increase in water temperature, DO decreases by 0.0286 mg/L. When both turbidity and water temperature are at 0, DO is present at levels of 9.37mg/L after Atlanta and at levels of 9.72mg/L before Atlanta. Although the best reduced model contained turbidity, water temperature, and location, the results indicated that only water temperature had a significant effect on DO levels. Figure 2 displays dissolved oxygen graphed over water temperature with the fitted model for both before and after Atlanta. We rejected the null hypothesis that the explanatory variables have no effect on DO levels. Overall, the model explains about 31% of the variation in the data (adjusted $R^2 = 0.307$).

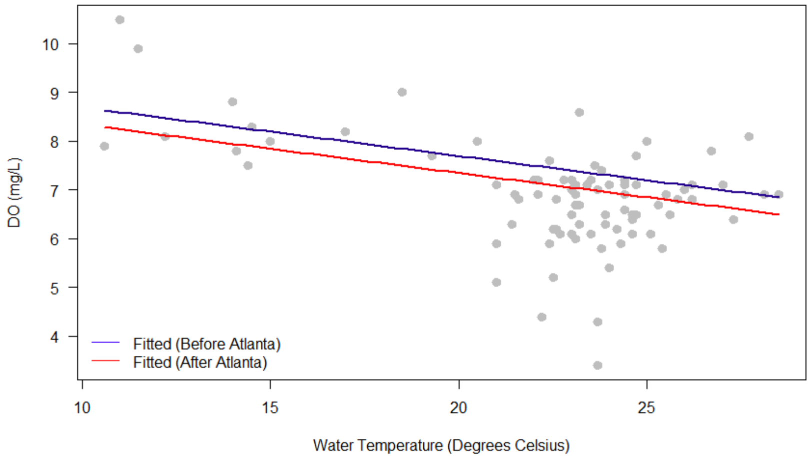

Figure 2 Multiple linear regression model of DO graphed over water temperature before and after metro Atlanta.

To confirm our model selection, we used the Akaike Information Criterion (AIC) test and the likelihood ratio test (LRT). The AIC test showed that our minimum adequate model had the lowest score, and the LRT showed that there was no significant difference between the full model and the minimum adequate model ($p > 0.5$). We checked assumptions using diagnostic plots, which showed that the residuals were close to a normal distribution based on the qqplot. Additionally, the residuals plot showed a scattering of points indicating homoscedasticity. The leverage plots showed no significant leverage from any of the points. We also tested the variance inflation factors (VIF) of the explanatory variables and found that they were all less than 2 indicating no multicollinearity.

Discussion

Our two-sample, two-way t-test results confirmed our initial expectation that DO levels differed upstream and downstream of Atlanta. Similarly, the results from our ANOVA test show that DO levels were higher upstream of Atlanta, which also supported our expectations.

As shown by Sanchez *et al*. (2007), water quality upstream of a metropolitan area is generally higher than water quality downstream of urbanized areas. This finding was further supported by the documented negative impacts of urbanization on DO levels and associated water quality due to urban-derived sources of pollution, such as municipal water discharge and industrial effluent (Gimenez, Lansac-Toha, and Higuti, 2015; Taka, Aalto, and Luoto, 2015; Frizzera and Alves, 2012; Nas and Nas, 2009; Goonetilleke *et al.*, 2005).

We included the factor of tributaries vs. mainstem sampling sites in our ANOVA to examine whether there was a significant difference in the water quality between the tributaries that feed the river and the mainstem of the river itself. Other studies have shown that due to differences in hydrology, geomorphology, and other natural processes, DO can strongly differ between tributary and mainstem sites (Bailey and Ahmadi, 2014). Our results, however, did not show a significant difference between waterbody type, so we did not include this factor in our linear model design.

The results of our multiple linear regression analysis showed that although not all of our explanatory variables had a significant effect on DO levels, water temperature was shown to have a strong negative correlation with DO levels. This fits with our expected results and is supported by studies of the relationship of DO and water temperature that demonstrate that warmer water has a lower capacity for dissolved oxygen (Taka, Aalto, and Luoto, 2015). Urban areas contribute considerable amounts of thermal pollution to waterways. Pavement and rooftops, due to their dark color, absorb solar radiation, and as water travels over these hot surfaces and enters urban streams, stream water temperature increases, consequently lowering DO levels (Taka, Aalto, and Luoto, 2015). Our results demonstrate that thermal pollution from the major metropolitan area of Atlanta may be contributing to decreased dissolved oxygen levels, and consequently, reduced overall water quality and ecosystem health. Although the scope of our study is limited to a section of the Chattahoochee River around Atlanta, it is likely that this trend can be seen in other urban areas. Urban planners and developers should consider the consequences of thermal pollution when establishing development regulations and choosing construction materials.

We were surprised that water temperature was the only significant explanatory variable in our linear model. However, it is worth noting that although turbidity was not statistically significant at a level of $p<0.05$, it did have small p-value of 0.08, which may indicate that turbidity in our model has practical significance, even though it was not statistically significant. Our model showed a negative effect of turbidity on DO as shown in Figure 3. High turbidity levels are often an indicator of high levels of runoff, and high levels of urban runoff include pollutants that likely lower dissolved oxygen.

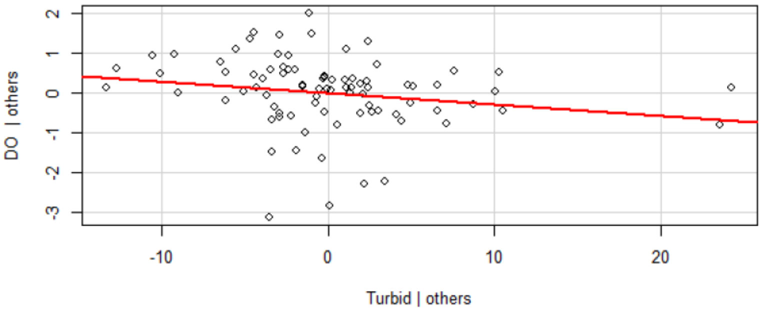

Figure 3 Added variable plot showing the effects of turbidity on DO with the other variables held constant.

We were also surprised that conductivity did not have a significant effect on dissolved oxygen levels. Usually sources of urban pollution and runoff contribute to higher conductivity levels, so it is expected that if conductivity levels are higher, dissolved oxygen should likely be lower. Our results, however, did not indicate that this was an observable trend in this dataset.

Based on our preliminary research, we also expected there to be a significant effect of pH on DO. Studies have found that low pH levels were correlated with lower DO levels (Frizzera and Alves, 2012). However, in our study we did not find a significant correlation between pH and DO. Perhaps due to unknown factors, such as natural processes not examined in this study, the effect of pH on DO is not significant in the sampled section of the Chattahoochee River.

Based on the adjusted R^2 value of 0.307, our best model explains approximately 31% of the variation in the data. The R^2 indicates that there are unexplained variables that were not considered in our study. In order to develop a better model for dissolved oxygen, it would be helpful to have data collected from multiple rivers, especially similarly sized rivers that pass through urban areas. Additionally, having more data from other rivers would ensure that the samples were independent. Although new tributaries joined the river between each mainstem site, sampling locations were still not entirely independent because sites downstream were impacted by some of the same factors that affected upstream samples. Due to the realistic limitations of field data collection, there was very little we could do to control for these effects.

Conclusion

In conclusion, our results indicated that mean DO levels were lower in sites downstream of Atlanta than in sites upstream of Atlanta. However, the mean DO levels were greater than the state standard both upstream and downstream of metro Atlanta, which is encouraging because this indicates that Atlanta is not contributing to severe degradation of water quality in this section of the Chattahoochee River.

Two variables that we did not investigate and that may be of interest for further study are the effects of seasonality and turbulence on DO levels. Nas and Nas (2009) found that DO levels were typically lower during the summer months due to the higher water temperatures as well as higher biological activity. Our study only examined data collected over the period of a week during the summer of 2014. Thus, to improve our study, it would be interesting to examine DO levels between sites over the space of a year to determine whether DO levels changed significantly between each sampling location outside of the summer months.

Additionally, Taka, Aalto, and Luoto (2015) found that stream channel turbulence had a positive effect on DO levels because the turbulence increased the water's capacity to absorb DO. As such, it would be worthwhile to investigate whether there were significant differences in stream channel turbulence between the two sampling sites, potentially due to a more natural stream corridor upstream of metro Atlanta and a more channelized stream corridor after metro Atlanta, and how this would affect DO levels between the two sampling locations.

Further studies that explore these effects as well as additional impacts of urbanization on water quality would be helpful in providing answers for some of the variance not explained in our analysis.

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