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Assessing Urbanization Impacts on Surface Water Quality in the Atlanta Region

by

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Under the Direction of Jeremy E. Diem, PhD

A Thesis submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science

in the College of Arts and Sciences

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ABSTRACT

Urbanization alters the quality of the natural environment, with more land areas that were previously covered with forest are now being converted to built-up areas. As a result, watersheds are typically negatively impacted by urbanization. This study analyzed multiple water-quality variables (i.e., temperature, turbidity, pH, dissolved oxygen, and conductance) in 24 to 30 watersheds in the Atlanta, GA region during 2014 – 2021. To understand the impact of urbanization on water quality, monthly means, correlations, and linear regression were used to investigate the relationship between water quality variables and watersheds characteristics. Landcover characteristics such as developed land, imperviousness, population and housing densities, increased stream temperature, and conductance, while decreased DO levels and turbidity. High temperatures and low dissolved oxygen can affect water quality, rendering it unsuitable for various uses. It is recommended that this approach for water quality assessment be used in other metropolitan areas.

INDEX WORDS: Watershed, Water quality, Urbanization, Urban streams, Rural streams, Land cover

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DEDICATION

I would like to dedicate this thesis to God Almighty who has given me the grace to come this far and provided my provisions to accomplish this program. I would also like to dedicate this to my beautiful wife Abiodun Tosin-Orimolade for her love and support while writing this thesis. I also dedicate this to my parents Mr. Olatubosun and Mrs. Kehinde Orimolade for providing me with moral support and the necessary resources to excel throughout my academic career.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DO – Dissolved Oxygen

LC – Landcover

NLCD – National Land Cover Database

TM – Thematic Mapper

MLRC – Multi-Resolution Land Characteristics

U.S. ACS – United States American Community Survey

USGS – United States Geological Survey

PCA – Principal Component Analysis

MLR – Multi-Linear Regression

uS/cm – Microsiemens per centimeter

Mg/L – Milligrams per liter

NTU – Nephelometric Turbidity Units

IMP – Imperviousness

PD – Population Density

HD – Housing Density

1 INTRODUCTION

Increasing urbanization is negatively impacting the environment. Urbanization is associated with population growth, economic development, and changes in the physical environment (Uttara et al., 2012), In 2018, around 55% of world's population resided in urbanized areas, and estimation of 68% of the world's population will live in urban areas by 2050. (United Nation, World Urbanization Prospects 2018). Urbanization leads to more imperviousness, which creates runoff and enhances the likelihood of pollutants being transported from land to water bodies (Gillies.,et al 2003; He, 2003; Wilson and Weng, 2010). Urban areas tend to have high concentrations of atmospheric pollutants, such as nitrogen oxides, carbon dioxide, ozone, and particulate matter, resulting from transportation and industrial activities (Chen et al., 2022; Goossens et al., 2021; Zhang et al., 2022). Urbanization has contributed to the loss of natural habitat and declining rate of biodiversity (He et al., 2014). In addition, natural habitats destruction and ecosystem fragmentation can decrease ecosystems' potential from providing important services like natural filtration of polluted water (Faulkner, 2004).

It could be argued that urbanization has its largest impact on water, especially water quality. Urbanization impacts the availability and safety of drinking water, the health of aquatic ecosystem, and the recreational use of waterbodies (Gillies, et al 2003; Brooks et al, 2012; and Zhang, et al 2007). Surface runoff, pollutant transport, and wastewater generation can significantly impair water quality in the urban areas (Mallin et al., 2009), thereby causing urban streams to have higher concentration of pollutants than rural streams (Lewis et al, 2007). In addition, leaking sewer systems in urban areas can introduce nitrate to surface waters (Wernick, et al., 1998).

Urban streams have relatively low dissolved oxygen (DO). With several studies carried out to investigate urbanization impact on water quality, it was observed that DO levels in urban areas are reported to be in the range of 0.73 – 7.10mg/l, while in rural areas, the DO levels are higher, ranging from 7.2 – 7.66mg/l, showing a consistent agreement that low DO is associated with urban waters due to organic pollutants, nutrient deposition, and higher stream temperatures in urban streams (Tu, 2011; Glinska-Lewczuk et al., 2016; Bakure et al., 2020). Forested watersheds have higher dissolved oxygen (DO) levels of not less than 7.5mg/l, whereas urbanized watersheds have DO levels as low as 0.32mg/l, indicating that forests play a significant role in the natural filtration of nutrients. (Ding et al., 2016; Bakure et al., 2020). The dominant cause of low dissolved oxygen in urban waters is associated with high nutrients deposition from human activities, such as leaks from sewage treatment plants, waste from pet, and industrial effluents, for instance, sewage discharge into stream can be a large source of nutrients and reduced water DO (Li et al., 2020).

No clear consensus exists on whether urbanization increases or decreases water pH. However, it is undeniable that there are factors affecting pH levels in urban streams, such as higher deforestation and sewage effects (Couceiro et al., 2007), discharge of acidified wastewater from industries and organic acids reduce pH in nearby streams (Popa et al, 2012). High stream pH levels above 7 are typically linked to the presence of soil minerals and nutrients, such as nitrogen and phosphorus from fertilizers and carbonate from mining activities (Ross et al., 2016). The pH levels in urban streams have been observed to drop as low as 3.2 due to acidic deposition and runoff. (O'Driscoll et al., 2010 ; Angelier, 2003; Herlihy et al., 1990; Kuyeli et al., 2009; Withanachchi et al, 2018). Untreated sewage released into urban streams also may slightly decrease pH (Norah et al., 2015).

Urbanization increases surface water temperature. It has been observed that impervious surfaces, which retain more heat, can lead to a rise in temperature (Nelson and Palmer,2007). The combined effects of surface runoff, wastewater inflows from industries and absence of stream shading, can cause higher stream temperatures, in particular, the absence of riparian vegetation has been found to cause a rise in annual maximum stream temperature of approximately 4°C (Herb et al, 2008 and Sun et al., 2014). Urbanization has caused some streams to increase in temperature up to 8.5°C (Pluhowski, 1970). Other research has shown urban streams to be 3°C warmer than forested streams (Gardiner et al, 2009; Somers et al. 2013).

Urban streams have higher conductivity than rural streams. Conductivity is defined as the ability of water to conduct electricity (Rusydi, 2018). High stream conductivity is an indicator of human disturbance, signaling potential pollution from substances like heavy metals or nutrients, which could have adverse effects on aquatic life and human health (Ackall et al., 2022). Increased runoff from urbanized areas often contains chloride, sulphate, nitrate, and suspended solids which can also increase water conductivity (Fashae et al. 2019, Wang et al. 2020); therefore, urban streams have been found to have at least twice the conductivity of rural streams (Busse et al., 2006, Yuan et al., 2019). For example, the deicing of roads in urban areas can be a major source of chloride in urban streams (Kushal et al., 2005). Also, it has been observed that urban streams display a steady positive correlation between conductance and presence of calcium and magnesium (Kaushal, et al 2018). The conductivity of urban streams has been noted to be at least four times higher than the conductivity of rural streams, with land use being identified as a contributing factor to this observation (Kellner et al. 2018).

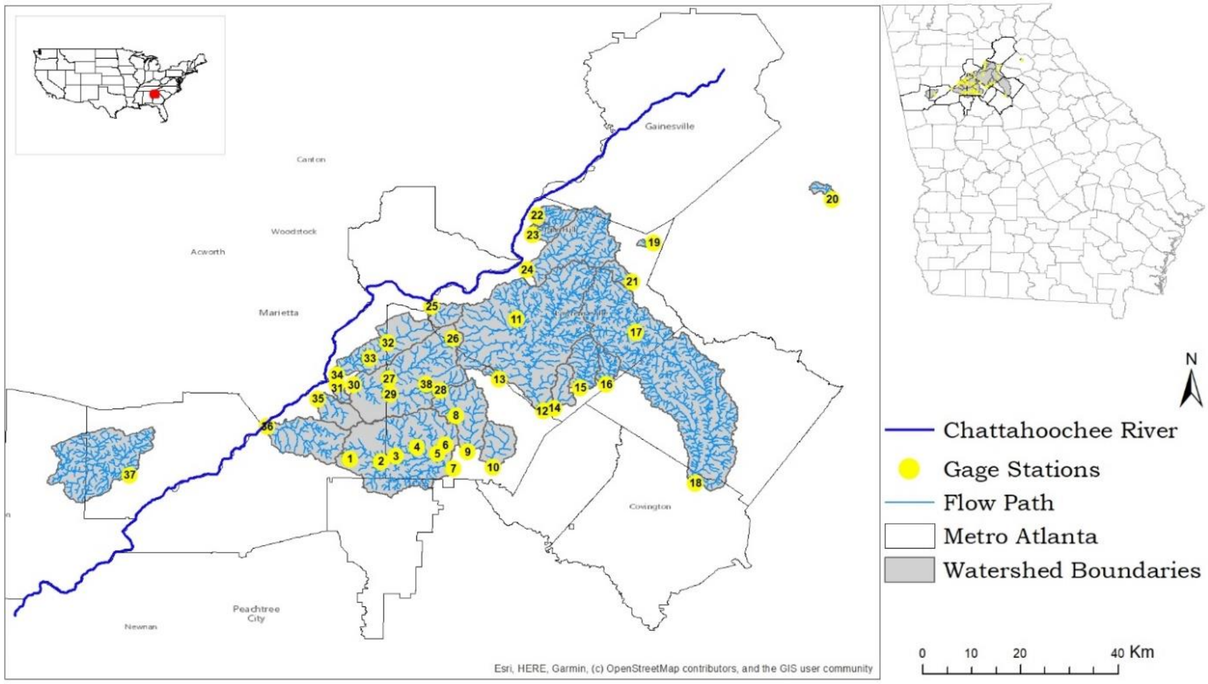
Urban streams have higher water turbidity compared to rural streams. High turbidity is linked to high nitrate and phosphate concentration from fertilizers applied to lawn in urban areas, runoff, erosion, and sedimentation caused by activities such as construction, road building, and land development (Ackall et al., 2022; White and Greer, 2006). One study has found turbidity of urban streams to be ~70% higher than the levels for rural streams (Antoneli et al. 2021). A study reported that the sediment concentration in a forested catchment was 51mg/l, whereas in an urban catchment, it was 67mg/l (Lenat and Crawford, 1994). Although the variation between the two concentrations was not significant, the higher sediment deposition observed in urban areas is consistent with the increased runoff often observed in urban areas. Another study found that sediments have a notable influence on turbidity levels. The study demonstrated that rural streams had an average turbidity of 10 NTU, whereas urban streams exhibited an average turbidity of 120 NTU, reflecting a substantial rise in turbidity, resulting from the intensification of suspended solids deposition in urban water (Hasenmueller et al., 2017).

1.1 Research Questions and Objectives

The extent at which water quality variables differ between urban and rural watersheds have not been fully studied in the Atlanta region. Seasonal variation in water quality between a substantial number of urban and rural watersheds have not been studied. Consequently, our knowledge of the effects of urbanization and other specific factors that affect surface water quality in the Atlanta region is not fully known. Hence, comprehensive investigation of the differences between a considerable number of urban and rural watersheds with respect to monthly mean values were considered in this study. The goal of this study is to determine how urbanization impacts the intra-annual variation in water quality. The objectives are to evaluate seasonal changes in water quality for types of watersheds and assess the relationship between urbanization and water quality.

1.2 Study Region

The chosen study region is the Atlanta-Sandy Springs-Gainesville combined statistical area (CSA) in the Southeastern United States (Figure 1). Of the 90 watersheds examined in Diem et al. (2021), 38 watersheds with varying sizes ranging from 2.11 to 291.29 km^2 had high-quality water-quality data and were thus used in this study (Table 1). The study region is situated in the piedmont physiographic province and characterized by underlying fractured crystalline rock features (Fanning and Trent, 2009), and all the watersheds have the same climate (humid subtropical). Winter and spring are typically the wettest months, due to strong rainstorms occurring, while summer months are generally drier, which can lead to water deficits (Stellman et al., 2001; Aulenbach and Peters 2018). The study area is an ideal study region as it possesses numerous streams with available water-quality data and all these streams share the same topography and climate.



Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 1 Study Region showing the positions of the watersheds within the Atlanta-Sandy Springs-Gainesville area, including the upper middle Chattahoochee, upper Chattahoochee, upper Flint, upper Ocmulgee, and upper Oconee among the 38 watersheds under study.

2 DATA AND METHODS

2.1 Data

Land-cover, population, housing, and water quality data were used. The land-cover data were retrieved from National Land Cover Database (NLCD). The NLCD is a comprehensive mapping tool that encompasses the entire United States and utilizes 30-meter satellite Images from Landsat Thematic Mapper (TM) to determine land cover. Also, the developed-imperviousness data for 2013, 2016, and 2019 were obtained from NLCD Database of the Multi-Resolution Land Characteristics (MLRC) Consortium. Population and housing data at block-group level were obtained from the U.S. Census Bureau's American Community Survey 5-year estimates for 2010 –2014 and 2015–2019 (U.S. ACS, 2022). The water quality variables (i.e., temperature, turbidity, pH, dissolved oxygen, and conductance) considered in this study were obtained from the USGS National Water Information Systems (USGS, 2022). The watersheds in the Atlanta region considered for this research were selected from the 90 watersheds examined by (Diem et al., 2021). Out of the 38 gauges watersheds used for this study, 24 watersheds had all the five water quality variables used in this study (Appendix A). The water quality data obtained for this study had some missing values, therefore the dataset was screened to remove data with less than 70% completeness as described below.

2.2 Methods

2.2.1 Grouping of Watersheds

The 38 watersheds were placed into groups based on the degree of urbanization. Four highly collinear land-cover variables (i.e, percent medium- intensity and high-intensity developed land, percent imperviousness, population density, and housing density) were selected for inclusion in a principal component analysis (PCA). The resulting PCA component scores for the watersheds was termed as urban score by (Diem et al., 2022).

2.2.2 Creation of Serially-Complete Water Quality Data

The water quality data obtained for this study had some missing values, therefore the dataset was screened. All gauges with <70% of data were excluded from the analysis, which retained 42% of gauges with data for further analysis. Linear regression was used to predict data for gauges with missing data in the 42% dataset, by using the most highly correlated gauges as predictors.

2.2.3 Pearson Correlation Analysis

The connection between watershed characteristics and water quality were assessed using correlation and regression. Pearson correlation test was used to measure linear dependency between monthly water-quality values and all watershed characteristics. The level of significance at 0.05 and 0.01 was chosen to determine the significance of relationship among the variables.

2.2.4 Linear Regression

The study utilized PCA to screen and determine variables with the highest components that were considered for the regression model. The land cover variables that were included in the PCA are open-space developed, low intensity developed, medium intensity developed, high intensity developed, deciduous, evergreen forest, mixed forest, hay/pasture, imperviousness, housing density, and population density. The variables with the highest loadings on the components were then used in the backward stepwise regression described below.

Multi-Linear Regression (MLR) was used to determine the relationship between the water quality and watershed variables. In the MLR model, a backward regression technique used all the independent variables and iteratively selected each of the variables at a step, and removed the variables that were not significant to the model. The MLR models were developed for each month/variable combination to determine the major controls of water quality and to identify outliers in Atlanta watersheds.

R-squared, residuals and standardized slope coefficient were used to evaluate the performance of the regression model. R-squared was used to determine the power of the MLR models on the water quality variables, and explained the variables used in the model analysis (Figure 10). Residuals of the regression analysis was used to determine the differences between the observed and predicted variables. Spatial autocorrelation was used to assess the possibility of spatial pattern in the residuals of the regression model, by considering Moran's Index values of -1, 0, and +1 representing negative spatial autocorrelation, no spatial autocorrelation, and positive spatial autocorrelation, respectively (Table 1). Standardized slope coefficients were used to identify the variables that were used to predict the water quality variables across the months (Figure 11).

3 RESULTS

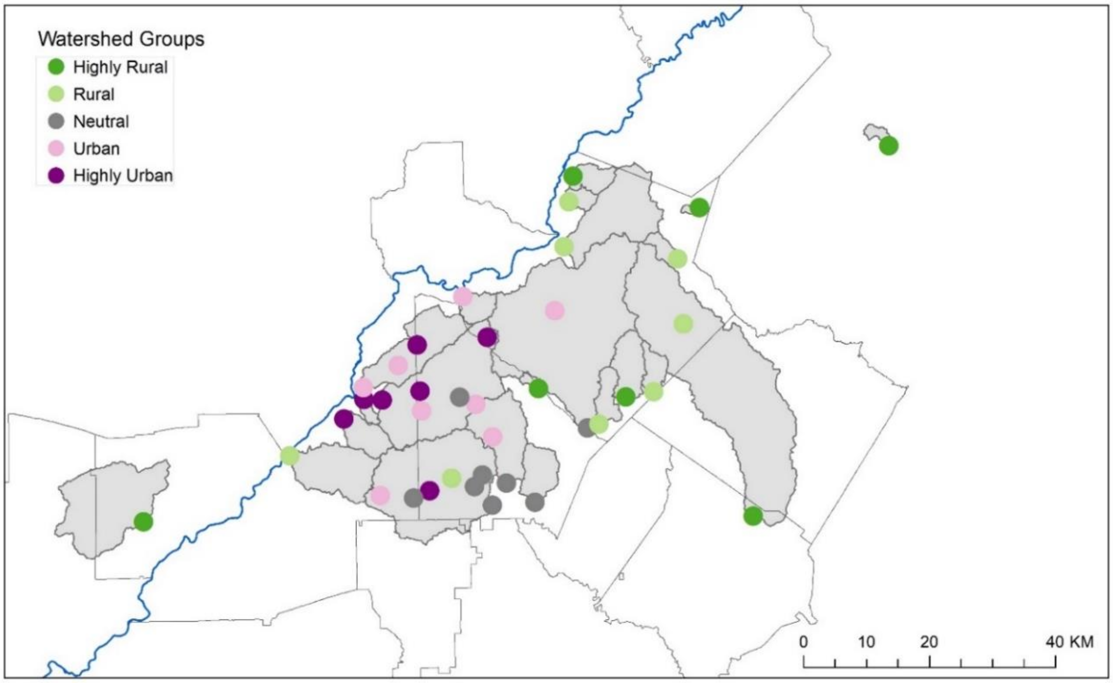


Figure 2 Map of watersheds in Group showing the least developed to highly urbanized watersheds in the Atlanta Region.

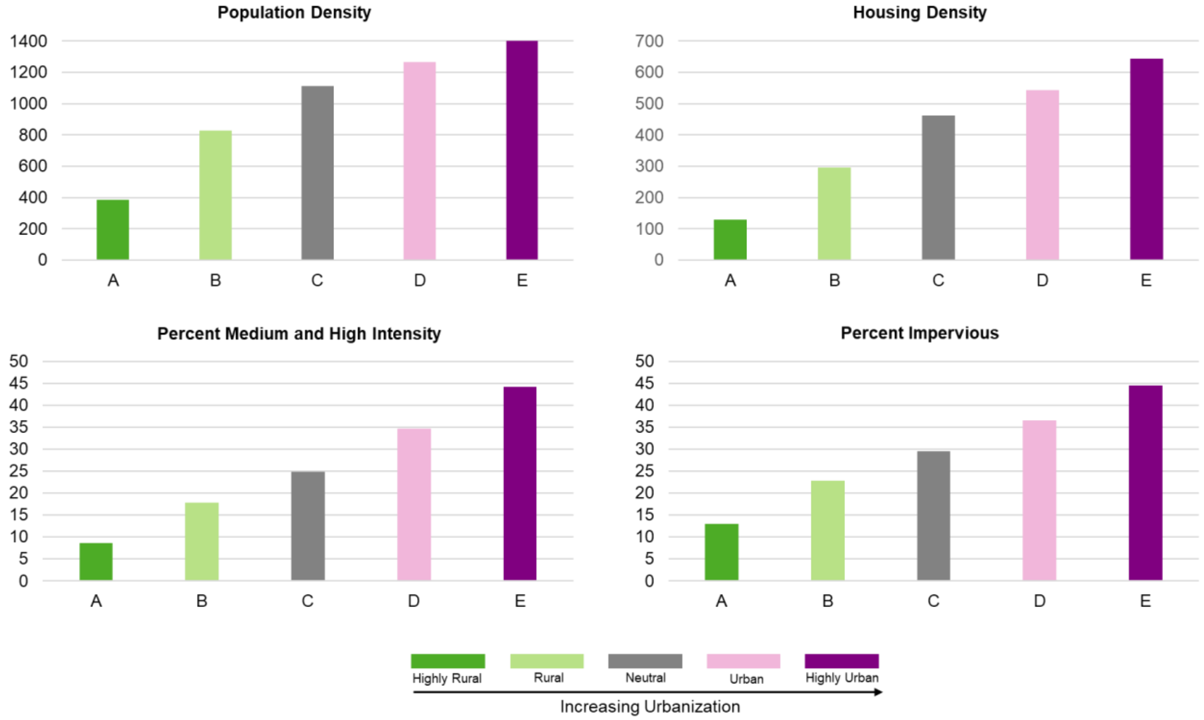


Figure 3 Landcover variables (i) Population density, (ii) housing density, (iii) percent medium and high intensity developed land area, and (iv) percent imperviousness, across rural – urban watersheds, showing level of development as (A) highly rural, (B) rural, (C) neutral, (D) urban, (E) highly urban, showing the level of development.

3.1 Watershed Groups

The watersheds were placed into five groups ranging from highly rural (Group A) to highly urban (Group E). Group E watersheds exhibit substantially higher population density, housing density, percent medium- and high- intensity, and percent imperviousness than Group A watersheds (Figure 3). The ranges in population density, housing density, percent medium- and high-intensity developed land, and percent imperviousness among the watersheds were 385 persons km-2 to 1400 km-2, 130 units km-2 to 644 units km-2, 9% to 44%, and 13% to 45%, respectively.

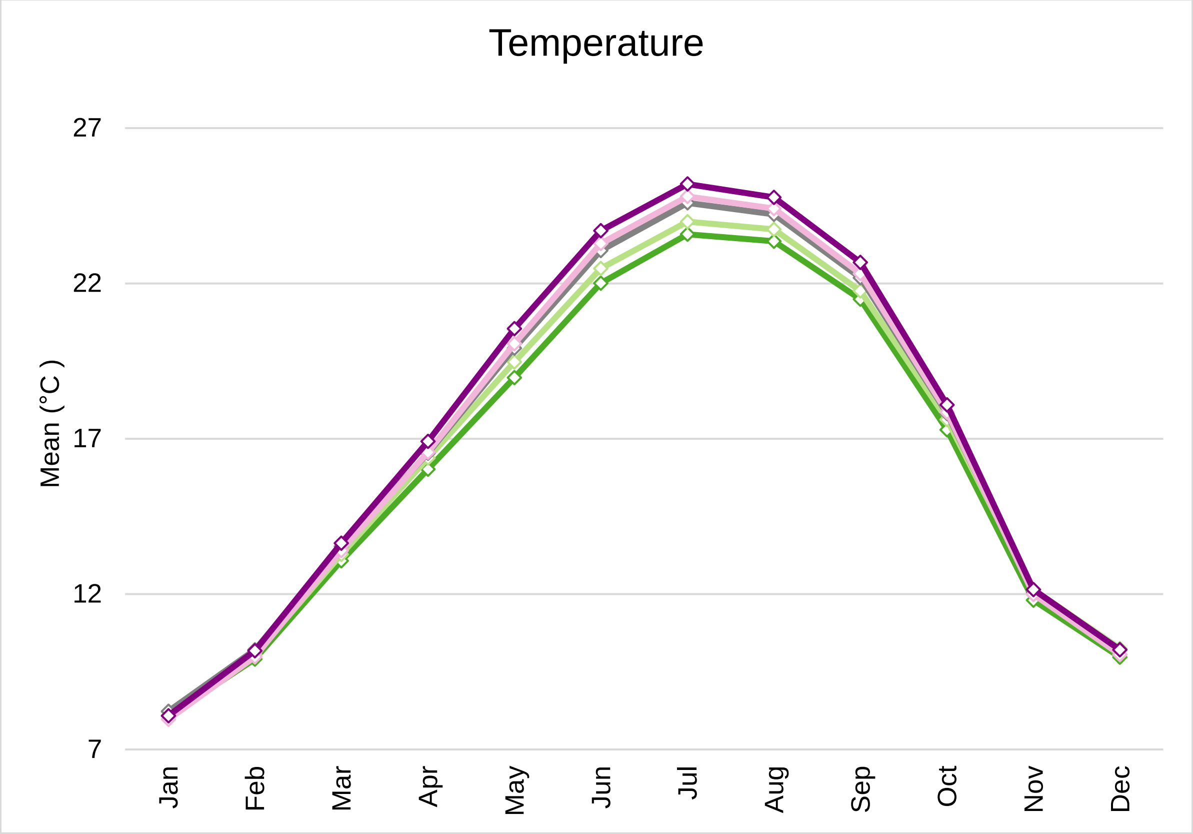


Figure 4 Mean daily values for each month showing relationship between temperature levels and urbanization.

3.2 Stream Temperature

The most urbanized watersheds consistently had the highest stream temperatures in the study region, while the least developed watersheds consistently had the lowest temperatures (Figure 4). The ranges of stream temperature in highly rural, rural, neutral, urban, and highly urban, were 7.3 - 23.5 °C, 7.3 – 24 °C, 7.5 – 25.4 °C, 7.8 – 25.4 °C, and 7.8 – 26 °C, respectively. In the wintertime, streams across all the watersheds had relatively equal temperatures with a difference of 0.5 °C between the most urbanized watersheds and most rural watersheds. While in summertime, stream temperature was about 2 °C warmer in the most urbanized watersheds than most rural watersheds.

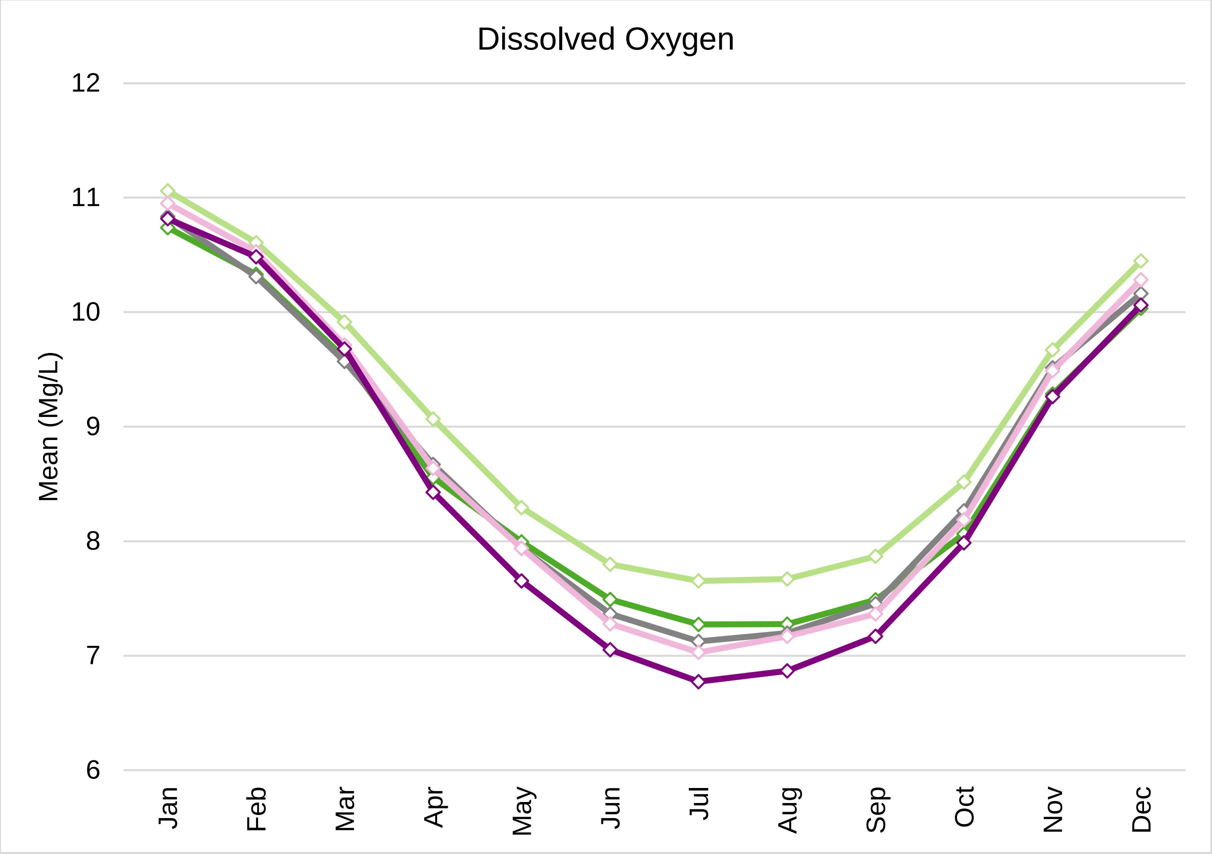


Figure 5 Mean daily values for each month showing relationship between dissolved oxygen levels and urbanization.

3.3 Dissolved Oxygen (DO)

Highly urbanized watersheds consistently had the lowest stream dissolved oxygen levels, while rural watersheds consistently had the highest dissolved oxygen (Figure 5). The dissolved oxygen levels for highly rural, rural, neutral, urban, and highly urban, were 7.3 – 10.7 Mg/L, 7.7 – 11.1 Mg/L, 7.2 – 10.8 Mg/L, 7.0 – 10.9, and 6.7 – 10.8 Mg/L, respectively. The rural watersheds had 0.3 Mg/L higher DO concentrations than the most urbanized watersheds in summer. The disparity increased in summer: rural watersheds had approximately 1 Mg/L higher DO concentrations than the most watersheds.

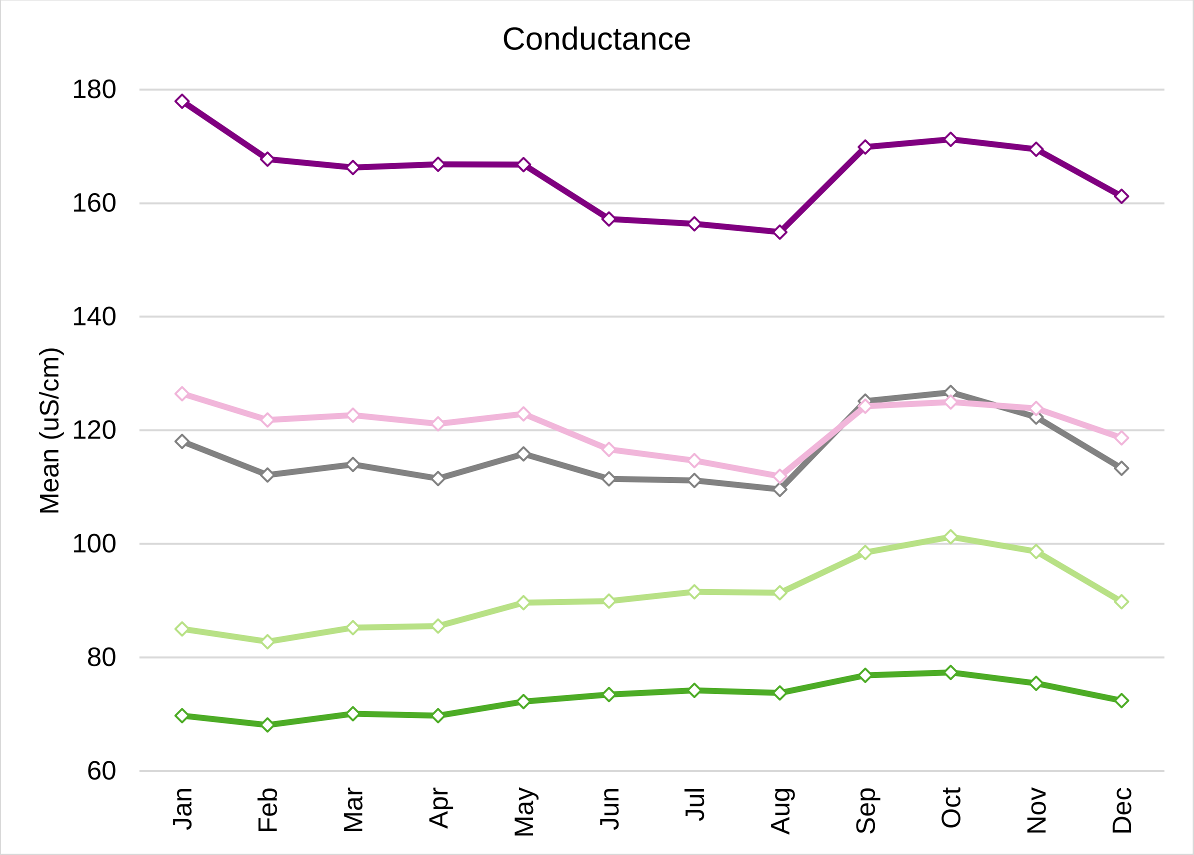


Figure 6 Mean daily values for each month showing relationship between conductance levels and urbanization.

3.4 Stream Conductance

The most urbanized watersheds consistently had the highest stream conductance, while the most rural watersheds consistently had the lowest stream conductance (Figure 6). The ranges of stream conductance in highly rural, rural, neutral, urban, and highly urban, were 68 – 78 uS/cm, 82 - 102 uS/cm, 109 – 127 uS/cm, 112 – 127 uS/cm, and 155 – 178 uS/cm, respectively. The peak conductance was generally observed between Fall (September – November). Highly urban watersheds had about 100 uS/cm conductance levels higher than the most rural watersheds in winter, and about 20 uS/cm conductance levels higher in the summertime.

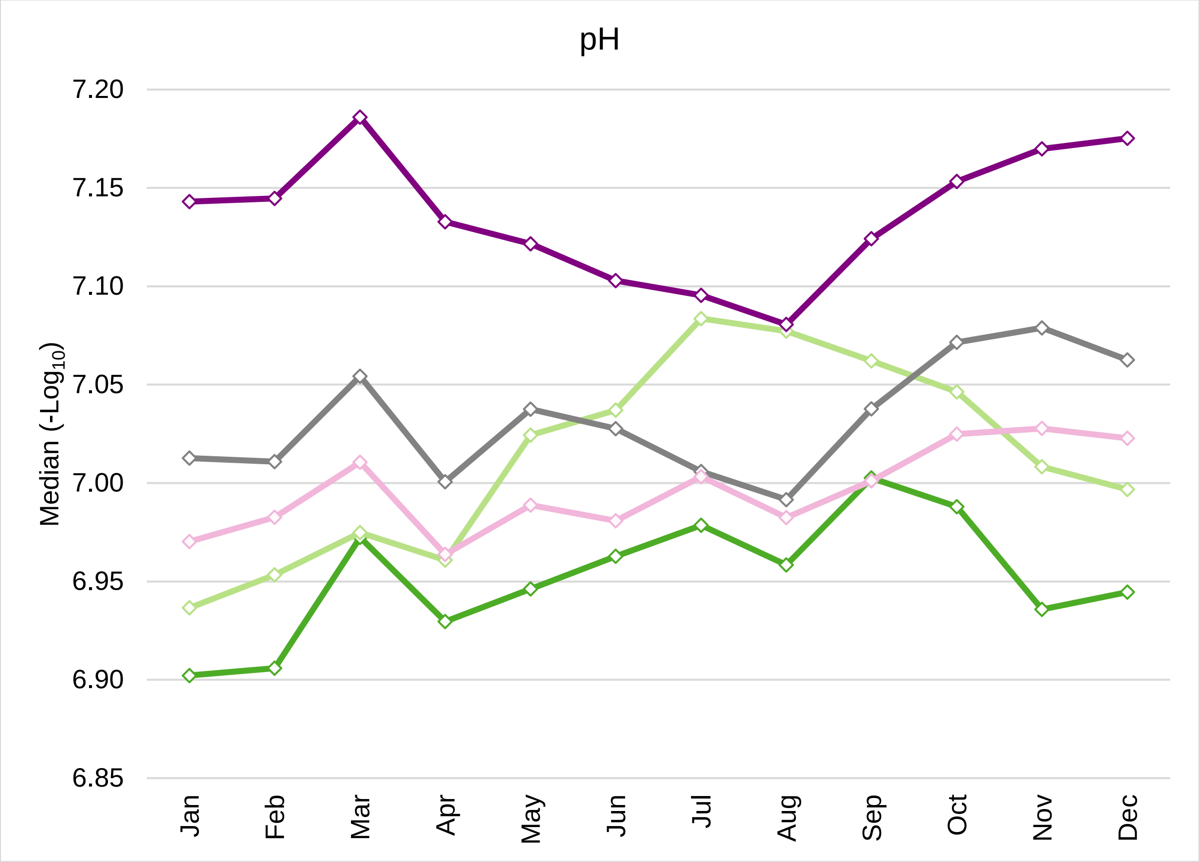


Figure 7 Mean daily values for each month showing relationship between pH levels and urbanization.

3.5 Stream pH

Highly urbanized watersheds had the highest stream pH, while the most rural watersheds had the lowest stream pH (Figure 7). The ranges in stream pH levels for highly rural, rural, neutral, urban, and highly urban, were 6.9 – 7.08, 6.93 – 7.08, 7.0 – 7.06, 6.97 – 7.03, and 7.08 – 7.18, respectively. The difference between the stream pH levels was more noticeable in the winter months. For the most urbanized watersheds, stream pH was lowest in summer and highest in winter. In contrast to the urban watersheds, rural watersheds had the highest stream pH in summer and lowest pH in winter. Therefore, the difference in pH between urban and rural watersheds was largest in winter and smallest in summer. The most urbanized streams had pH 0.25 more than rural streams in winter and pH 0.13 more in the summer.

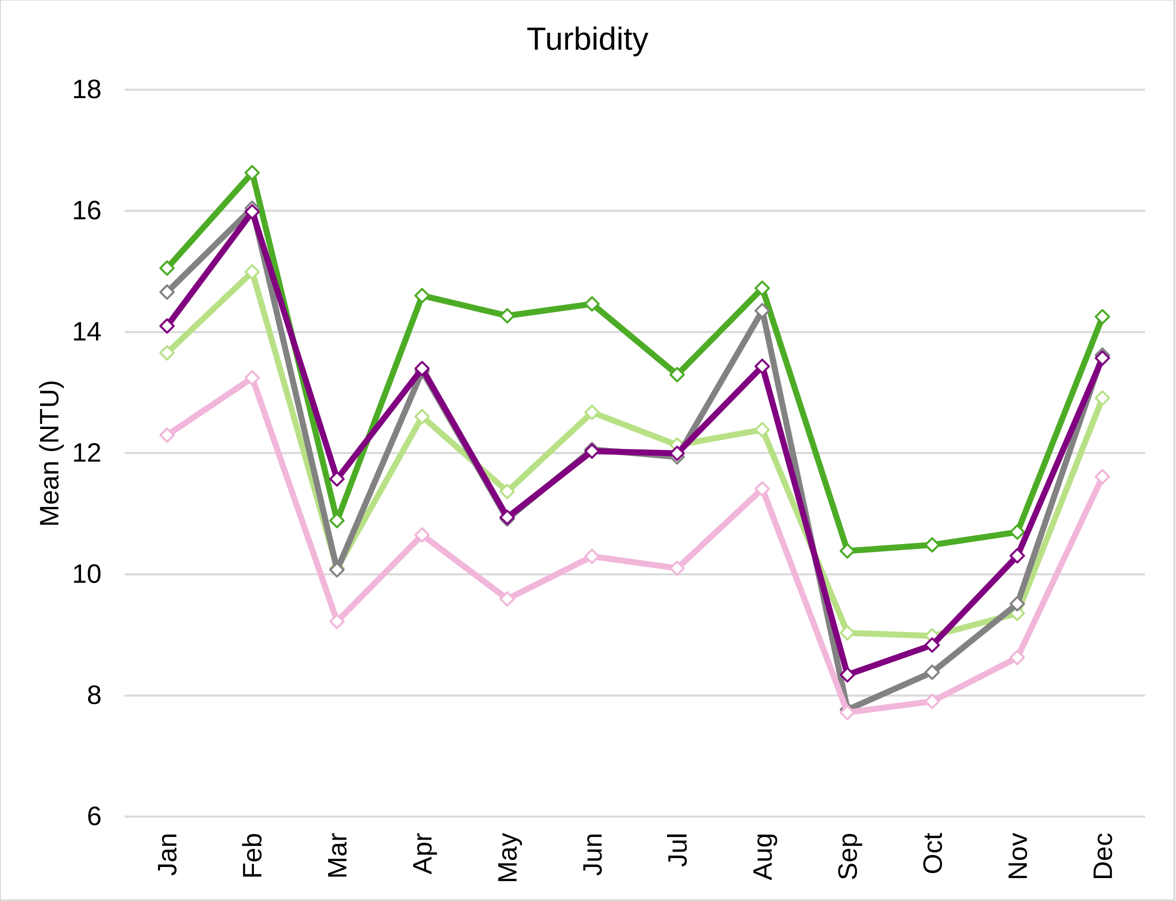


Figure 8 Mean daily values for each month showing relationship between turbidity levels and urbanization.

3.6 Stream Turbidity

The most rural watersheds had the highest turbidity, while urban watersheds had the lowest turbidity (Figure 8). The range in stream turbidity levels for highly rural, rural, neutral, urban, and highly urban, were 10.3 – 16.5 NTU, 10.0 – 13.0 NTU, 7.8 – 14.4 NTU, 7.8 – 13.2, and 8.3 – 16.0, respectively. Stream turbidity was generally highest in the winter, and lowest in the summer. In February, where stream turbidity had the highest value, the most rural watersheds had about 3 NTU turbidity higher than rural watersheds, while the most rural watersheds had about 1 NTU turbidity higher than the most urbanized watersheds. The difference in stream turbidity among the watersheds was more noticeable in April – August (warmer months).

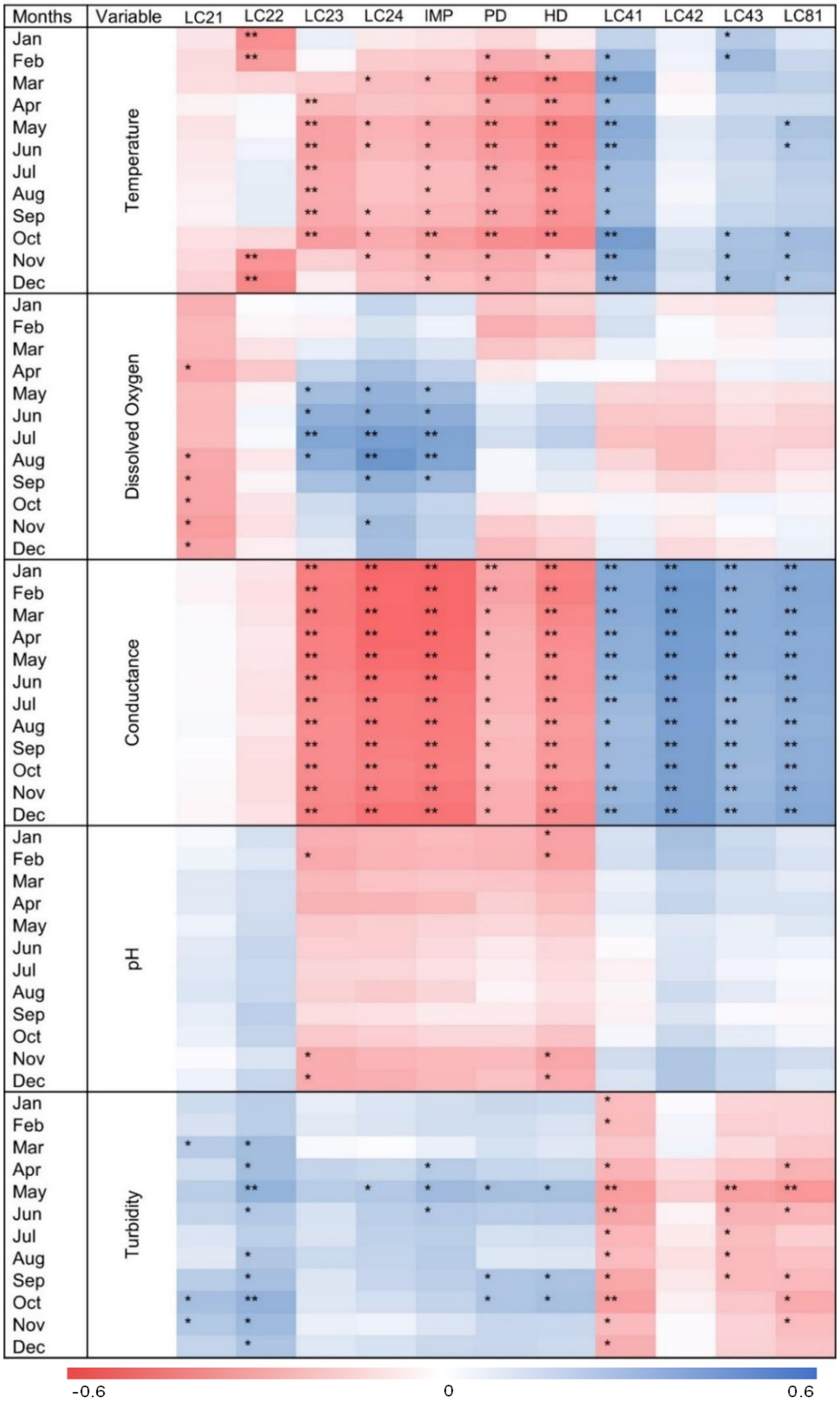


Figure 9 Correlation between Monthly Water Variables and Landcover (LC21 = Open-space developed, LC22 = Low intensity developed, LC23 = Medium intensity developed, LC24 = High intensity developed, IMP = Imperviousness, PD = population density, HD = Housing density, LC41 = Deciduous, LC42 = Evergreen forest, LC43 = Mixed forest, and LC81 = Hay/Pasture.)

3.7 Correlation Analysis

Temperature had a significant positive correlation with development (Figure 9. Temperature showed a positive correlation with low-intensity developed land in the winter months, while there was a weak negative correlation with low-intensity developed land in the summer months. Conversely, there was a weak negative correlation in the winter months and a moderate positive correlation in the summer months between temperature and medium-intensity developed land. Almost throughout the year, a positive moderate correlation was observed between temperature, high-intensity developed land, imperviousness, and population density. Temperature showed a negative correlation with deciduous, evergreen forest, mixed forest, and hay/pasture throughout the year, with no significant intra-annual variability.

DO had a significant negative correlation with development (Figure 9). DO positively correlated with open space and low-intensity developed land throughout the year but negatively correlated with medium-intensity developed, high-intensity developed, and imperviousness throughout the year. DO showed a slight positive correlation with population and housing density in the winter months and a weak negative correlation in the summer months. A slight positive correlation was recorded between DO, deciduous, evergreen forest, mixed forest, and hay/pasture, in the summer months, and a slight negative correlation in the winter months.

Conductance had a significant positive correlation with development (Figure 9). The winter months showed a weak positive correlation between conductance whereas, open space and in the summer months, conductance had a weak negative correlation with open space. Conductance had a positive correlation with open space developed, low-intensity developed, medium-intensity developed, high-intensity developed, imperviousness, population, and housing density throughout the year, while a conductance negatively correlated with deciduous, evergreen forest, mixed forest, and hay/pasture throughout the year.

pH had a positive correlation with development (Figure 9). pH had a slight negative correlation with open space developed, low intensity developed, deciduous, evergreen forest, mixed forest, and hay/pasture throughout the year, while pH positively correlated with medium intensity developed, high intensity developed, imperviousness, population, and housing density throughout the year.

Turbidity had a significant negative correlation with development (Figure 9). Turbidity negatively correlated with open space, low intensity developed, medium intensity developed, high intensity developed, imperviousness, population, and housing density throughout the year, with no significant intra-annual variability, while turbidity positively correlated with deciduous, evergreen forest, mixed forest, and hay/pasture throughout the year.

3.8 Regression Analysis

The PCA that was used for variable screening resulted in two components. The high loading variables on component 1 were LC23, LC24, LC42, LC43, and imperviousness. The high loading variables on component 2 were LC21, LC22, LC41, LC81, housing density, and population density. As noted in the methods section, the variable with the highest correlation from component 1 and the variable with the highest correlation from component 2 were used in a backward stepwise regression for each monthly water-quality variable.

Explained variance by MLR models varied considerably, with the highest explained variance for conductance and the lowest explained variance for pH. The model for temperature prediction had no significant difference across the months. DO was difficult to model in the winter months (January – March), while the explained variance for DO in summer (April-August) was slightly higher than other months. The model for conductance consistently performed well across all months. pH was difficult to model in the warmer months (March - October). The slight variance that was explained by the model for turbidity was consistent across all months.

The MLR estimates are considered reliable and can be used for inferential purposes because assumptions of regression were not violated. Important spatial variables were not excluded from the models. The MLR result showed that there was no significant positive spatial autocorrelation among the residuals for any of the MLR models, with small Moran's I value in the range of -0.09 to 0.13 (Table 1).

Temperature regression models included LC22, HD, and LC41 as predictors, with LC22 and HD having a positive coefficient and LC41 having negative coefficients (Figure 11). LC22 strongly predicted temperature in December – February, and HD predicted temperature in March – September, while LC41 weakly predicted temperature in October and November.

DO regression models had LC21 and LC24 as predictors, with LC21 having a positive coefficient and LC24 having a negative coefficient (Figure 11). LC21 strongly predicted DO in April, and October- December, while LC24 showed weak DO prediction in the summer months (May – September). The MLR models could not predict DO in January and February.

Conductance regression models had LC24, imperviousness, and HD as predictors, having a positive coefficient (Figure 11). LC4 predicted conductance in April, and imperviousness predicted conductance in February, March and May – December, while HD predicted conductance in January, respectively.

pH regression models included LC23, and HD as predictors, having positive coefficients (Figure 11). LC23 predicted pH only in December, while HD predicted pH in January, February, and November. pH could not be predicted for March – October.

Turbidity regression models included LC22, L41, and LC81 as predictors, with LC22 having a negative coefficient, and LC41and LC81 having positive coefficients (Figure 11). LC22 weakly predicted turbidity in March, April, August, and November. While LC81 predicted turbidity in May, and LC41 predicted turbidity in the remaining months of the year.

Table 1 Spatial Autocorrelation of Residuals

Variable	Moran's I Values
Temperature (winter months)	0.066812
Temperature (summers months)	0.054197
DO	-0.090598
Conductance	0.133473 *
pH	0.082672
Turbidity	-0.076866

Significance level (0.05) = *

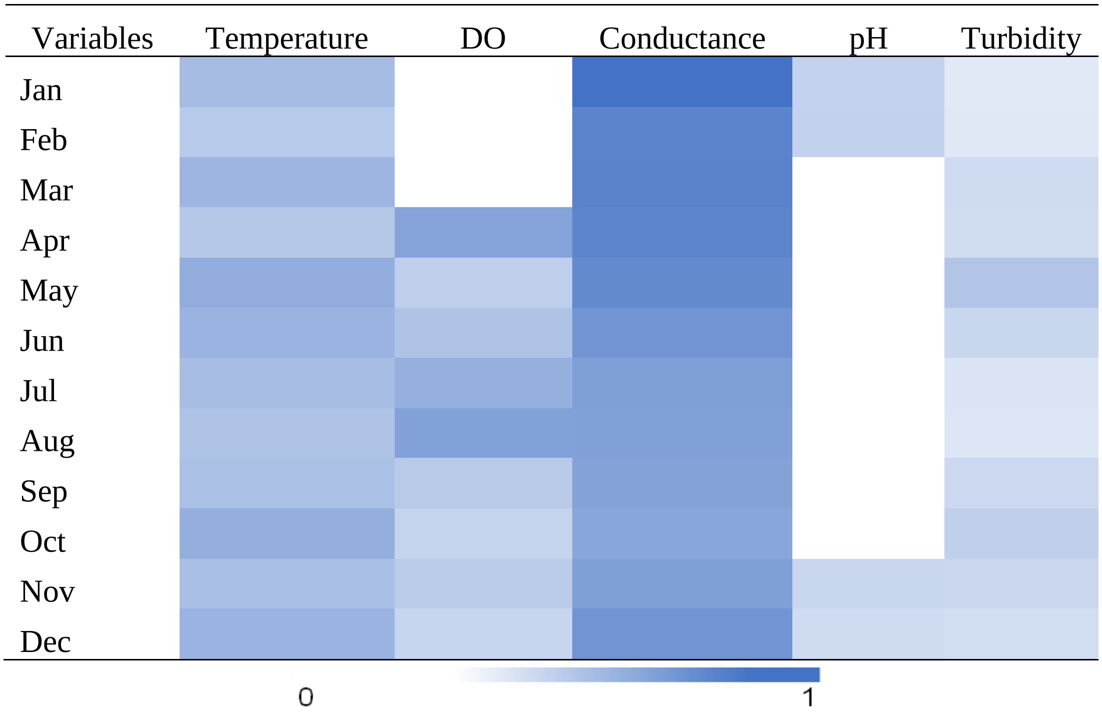


Figure 10 Coefficients of Determination (R-Squared)

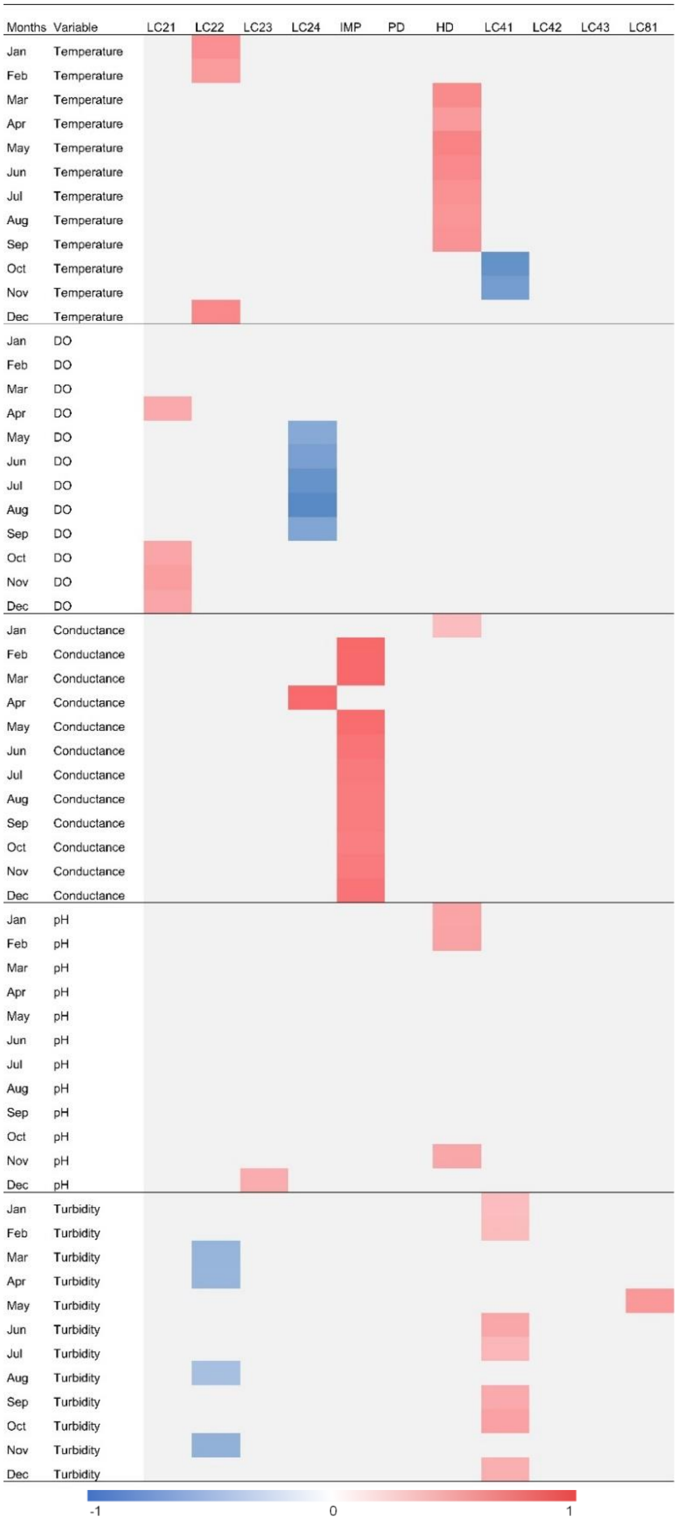


Figure 11 Standardized Slope Coefficients (LC21 = Open-space developed, LC22 = Low intensity developed, LC23 = Medium intensity developed, LC24 = High intensity developed, IMP = Imperviousness, PD = population density, HD = Housing density, LC41 = Deciduous, LC42 = Evergreen forest, LC43 = Mixed forest, and LC81 = Hay/Pasture.)

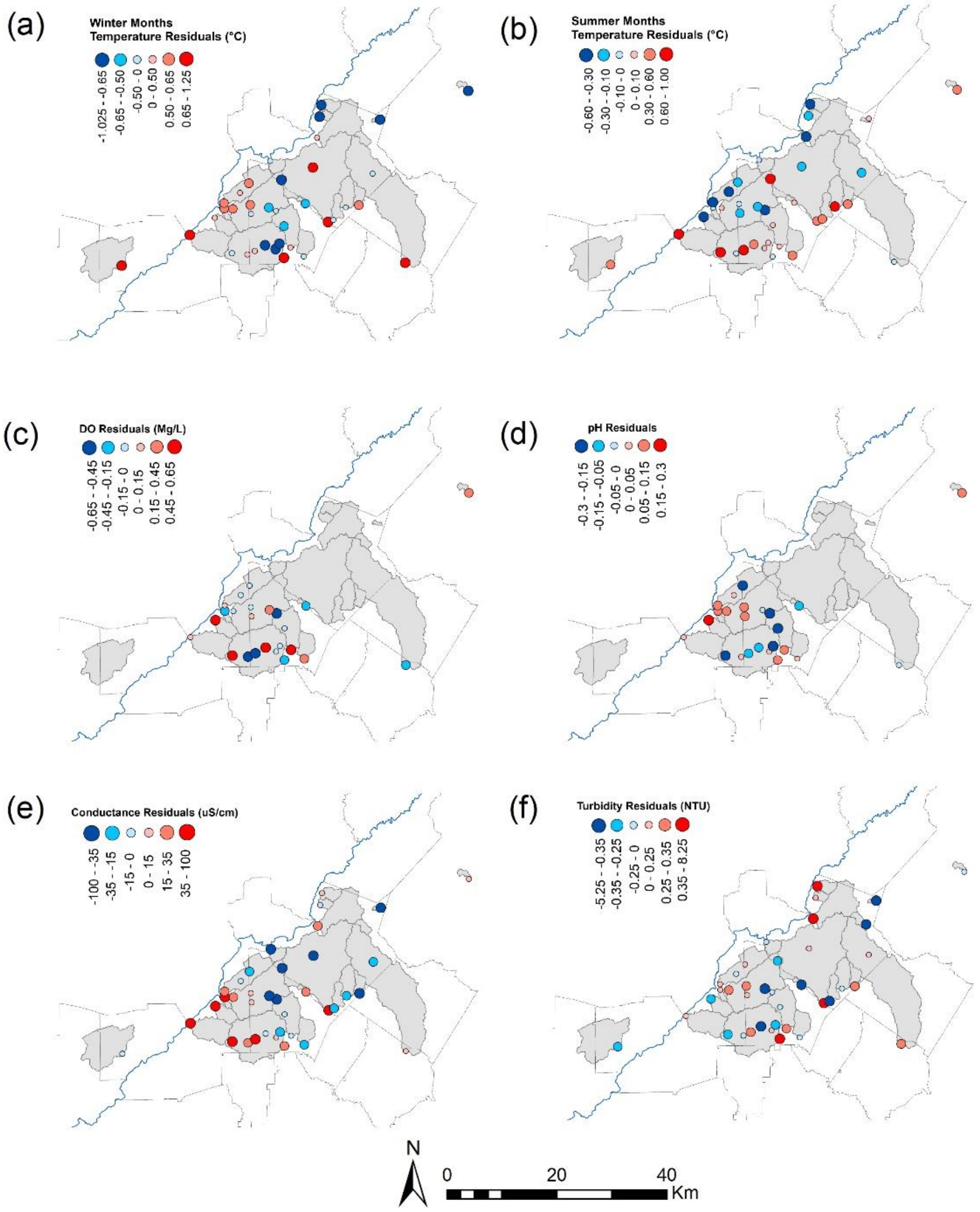


Figure 12 Residual Maps for (a) Winter months temperature, (b) Summer months temperature, (c) DO, (d) pH, (e) Conductance, and (f) Turbidity, showing distributions of residuals across the watersheds.

3.9 Spatial Variations for Residuals of Water Quality Variables

Large positive residuals were randomly distributed across the watersheds, with more residuals distributed in the central part of Atlanta (Figure 12). The concentration of the residuals in the central part of Atlanta shows that most of the water quality variables are higher in central Atlanta watersheds.

4 DISCUSSION

4.1 Urbanization increases stream temperatures and decreases dissolved oxygen, especially in summer.

Urban streams had higher temperatures and lower DO than rural streams, and the disparity was most pronounced during summer. These urbanizations have been observed in other studies (Li *et al.,* 2008; Li *et al.,* 2020; Glinska-Lewczuk, *et al.,* 2016; and Ngoye *et al.,* 2004). Seasonal variation in water temperatures is explained by reduced flow and solar radiation warming up impervious surfaces and body of the stream during summer. The pollution of surface streams with sewage discharge tends to increase the concentration of organic load and other nutrients in the streams and increase the oxidation and metabolic activities in the urban streams, thus decreasing DO concentration (Li *et al.,* 2020; Glinska-Lewczuk, *et al.,* 2016). In addition, stream temperature and DO change significantly with some anthropogenic activities such as application of pesticide, different water use, and impact of climate change (Tu, 2011). For rural watersheds, all streams also had peak temperature and DO concentration in the summer, which is attributed to intense solar radiation and biological activities in the stream (Ngoye et al, 2004). Considering the stark contrast between high temperature and low dissolved oxygen, this study revealed an inverse relationship coexisting between temperature and DO across all the seasons, comparably, stream temperature decreased and DO increase in the winter-early spring months, while stream temperature increases and DO decreases in summer months (USGS, 2018).

4.2 Urbanization Increases stream conductance

Urbanization increases in conductance, which has been shown in other studies, the high conductance value observed in urban streams is similar to previous findings of (Rusydi, 2018, Ackall et al., 2022; Kushal et al., 2005) which explained that dissolved solutes like sodium chloride, wastewater and weathering of concrete surfaces are major factors contributing to high conductance in urban streams. It was observed that the stream conductance in urban watersheds was three times more than the rural watersheds, this large difference indicated that more sediments and nutrients are contributing to urban stream conductance, as reported by (Bakure et al., 2000; Chusov et al., 2014). Another study highlighted that nitrate concentration in urban areas can significantly raise conductance value in urban streams (Bakure et al., 2000; Cummingham et al., 2010). Also, wastewater from sewers and residential areas can raise conductance level in urban streams (Chusov et al., 2014). The nutrients load such as nitrate, phosphate, and dissolved solids contribute to high conductance in stream (EPA, 2018), which are generated from human activities such as discharge of untreated sewage, industrial discharge, and pesticide applications, as well as natural cause like the geology composition of the watersheds (Fashae et al. 2019; and Cummingham et al., 2010). It was generally observed that all watersheds had the highest stream conductance value in the Autumn, which is likely caused by low water flow and high nutrients as explained by (Erina et al., 2020) and substantial decline in water levels according to (Navratilova, and Navratil, 2005).

4.3 Urbanization increases stream pH

It was observed in this study that urbanization increases stream pH. Weathering of impervious surfaces explained stream pH increase in the urban areas (Kaushal et al., 2013). However, from previous studies, there is a trend of argument which does not establish that development significantly increases stream pH in urban streams, as it was reported that rural streams had higher pH concentration than some urban streams (Driscoll et al., 2001; Kuyeli et al., 2009; Peters, 2009; Kuhl et al., 2010; and Hamid et al 2020; Khatri and Tyagi, 2014). Both urban and rural share similar factors that control pH, such as evapotranspiration, biological activities, geological component, soil types, bedrock materials that are rich in carbonates materials which serve as buffers and increases pH concentrations in streams (Hamid et al., 2020). Also, increased anthropogenic activities such as mining, acidic nutrients from industries, and biological activities of organisms in urban streams can reduce stream pH concentration (Khatri and Tyagi, 2014; Gomez Isaza et al., 2020). The seasonal dynamic of pH concentration in urban and rural streams is partly explained by high temperature and precipitation (Hamid et al., 2020). During summer, local precipitation contributes slight acidic water concentration into streams as precipitation is slightly acidic (USGS, 2019) which causes pH depression. High temperatures enhance biological activities that break down organic material and release CO2 in the stream, thus contributing slightly to stream acidification (Ahmid et al., 2019). The observed stream pH rise in rural watersheds during summer raises a signal that there might be some potential factors contributing to high pH in the watersheds, similarly high pH concentration in rural stream is likely associated with high alkaline constituents and absence of high acidic nutrients as reported by (Driscoll et al., 2001). The marked difference observed in stream pH in the urbanized watersheds during spring compared to rural watersheds is likely due to decreasing temperatures and anthropogenic pollutants such as sewage waste (Xu et al., 2019; Khatri and Tyagi (2015).

4.4 Urbanization increases stream turbidity

The hypothesis for this study posited that turbidity correlates with urbanization, however, the results contradict the hypothesis and some previous studies that recorded higher turbidity in urban streams than in rural streams (Antoneli et al., 2021; Hasenmueller et al., 2017; White and Greer, 200). Although, it is not rare for rural streams to have higher turbidity than urban streams, due to heavy and continuous stormflow which potentially causes sediment disturbance or resuspension in rural streams (Coulliette and Noble 2008). Higher stream turbidity observed in rural watersheds in winter months, is related to high runoff and erosion of dissolved solutes, suspended solids, sediments, and particulates that are generated from human activities into rural streams (Coulliette and Noble 2008; Ackall et al., 2022; and USEPA, 2018). There was a noticeable increase in rural-urban stream turbidity in the warm season which is likely caused by high suspended materials from organic decomposition, suspended sediments driven by surface erosion, and high activities of aquatic organisms that reduce dissolved oxygen in the stream. (Duncan et al., 1987; and Evans-White et al., 2009).

5 CONCLUSION

The objective of this research was to examine how urbanization impacts water quality. The study region was the Atlanta, GA metropolitan area. Water-quality data from 2014 – 2021 and landcover data from NLCD were subjected to statistical analysis. The monthly analysis provided a valuable summary of seasonal trends in the water quality variables across the watersheds, while results from inferential statistics provided insights on the relationship between urban components and their influence on urban streams. The main findings show that urban streams have higher temperatures, lower DO, higher conductance, higher pH, and lower turbidity than rural streams. Urban heat, development, and several human activities cause higher temperatures in urban streams. Need a sentence about what causes higher temperatures in urban streams. An increase in stream temperature reduces DO in streams. This relationship is an important phenomenon in explaining stream quality dynamics and understanding factors that possibly control both stream temperature and DO in urban watersheds. Urbanization significantly increases stream conductance due to high nutrients and sediments transport into urban streams. Most of the nutrients associated with high conductive capacity are dissolved ions sourced from various human activities like mining, road deicing, and sediments erosion in urban watersheds. Hight stream pH concentration which indicates alkalinity can also be influenced by urbanization, due to carbonates and other basic constituents from human activities. Higher turbidity in rural streams is likely due to high continuous river erosion and sedimentation. It is recommended that the techniques used for this research be repeated in other metropolitan areas.

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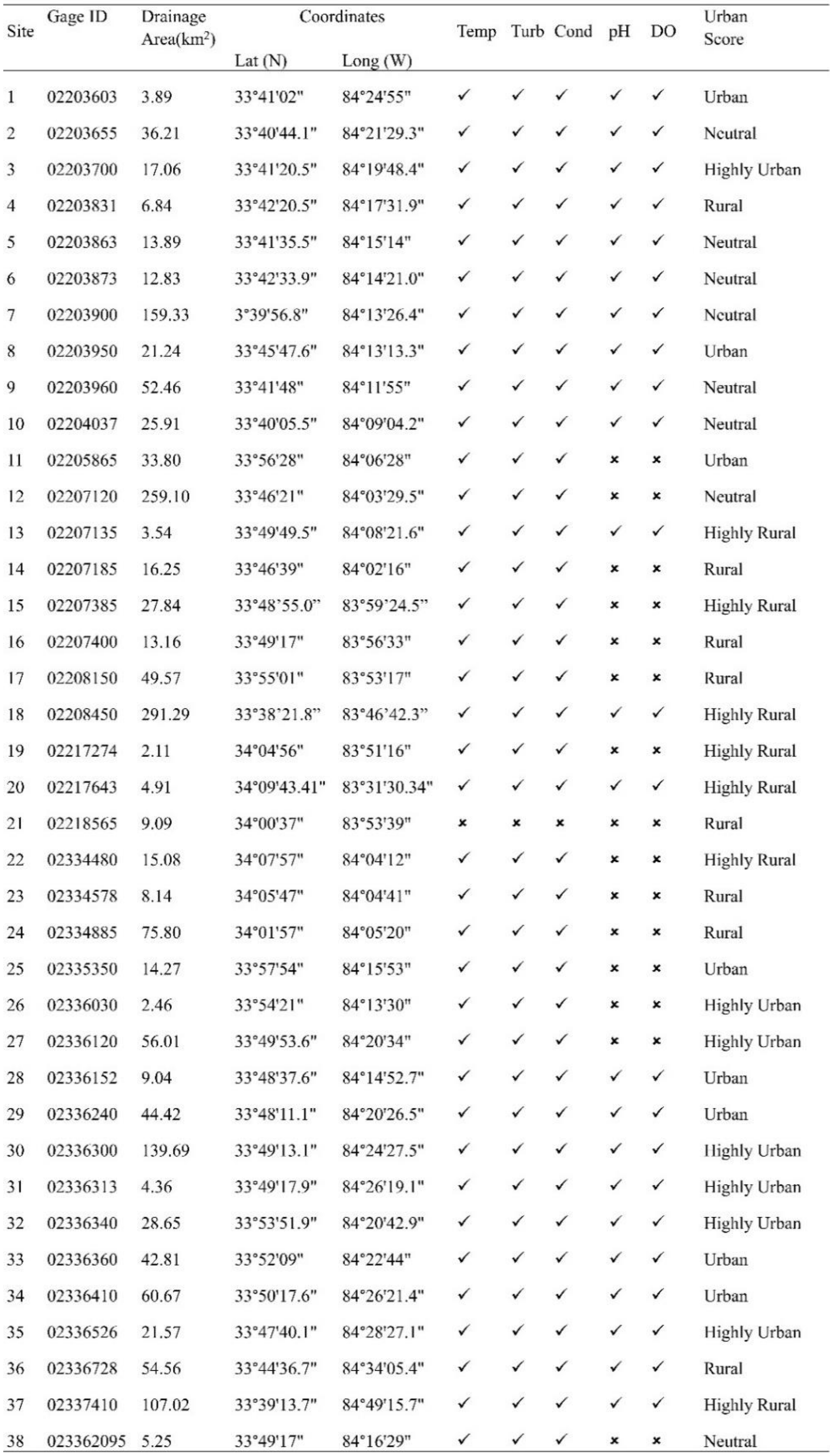
APPENDICES

Appendix A Site Data Specific Descriptions



Site	Gage ID	Drainage Area(km^2)	Coordinates		Temp	Turb	Cond	pH	DO	Urban Score
			Lat (N)	Long (W)						
1	02203603	3.89	33°41'02"	84°24'55"	✓	✓	✓	✓	✓	Urban
2	02203655	36.21	33°40'44.1"	84°21'29.3"	✓	✓	✓	✓	✓	Neutral
3	02203700	17.06	33°41'20.5"	84°19'48.4"	✓	✓	✓	✓	✓	Highly Urban
4	02203831	6.84	33°42'20.5"	84°17'31.9"	✓	✓	✓	✓	✓	Rural
5	02203863	13.89	33°41'35.5"	84°15'14"	✓	✓	✓	✓	✓	Neutral
6	02203873	12.83	33°42'33.9"	84°14'21.0"	✓	✓	✓	✓	✓	Neutral
7	02203900	159.33	3°39'56.8"	84°13'26.4"	✓	✓	✓	✓	✓	Neutral
8	02203950	21.24	33°45'47.6"	84°13'13.3"	✓	✓	✓	✓	✓	Urban
9	02203960	52.46	33°41'48"	84°11'55"	✓	✓	✓	✓	✓	Neutral
10	02204037	25.91	33°40'05.5"	84°09'04.2"	✓	✓	✓	✓	✓	Neutral
11	02205865	33.80	33°56'28"	84°06'28"	✓	✓	✓	×	×	Urban
12	02207120	259.10	33°46'21"	84°03'29.5"	✓	✓	✓	×	×	Neutral
13	02207135	3.54	33°49'49.5"	84°08'21.6"	✓	✓	✓	✓	✓	Highly Rural
14	02207185	16.25	33°46'39"	84°02'16"	✓	✓	✓	×	×	Rural
15	02207385	27.84	33°48’55.0”	83°59’24.5”	✓	✓	✓	×	×	Highly Rural
16	02207400	13.16	33°49'17"	83°56'33"	✓	✓	✓	×	×	Rural
17	02208150	49.57	33°55'01"	83°53'17"	✓	✓	✓	×	×	Rural
18	02208450	291.29	33°38’21.8”	83°46’42.3”	✓	✓	✓	✓	✓	Highly Rural
19	02217274	2.11	34°04'56"	83°51'16"	✓	✓	✓	×	×	Highly Rural
20	02217643	4.91	34°09'43.41"	83°31'30.34"	✓	✓	✓	✓	✓	Highly Rural
21	02218565	9.09	34°00'37"	83°53'39"	×	×	×	×	×	Rural
22	02334480	15.08	34°07'57"	84°04'12"	✓	✓	✓	×	×	Highly Rural
23	02334578	8.14	34°05'47"	84°04'41"	✓	✓	✓	×	×	Rural
24	02334885	75.80	34°01'57"	84°05'20"	✓	✓	✓	×	×	Rural
25	02335350	14.27	33°57'54"	84°15'53"	✓	✓	✓	×	×	Urban
26	02336030	2.46	33°54'21"	84°13'30"	✓	✓	✓	×	×	Highly Urban
27	02336120	56.01	33°49'53.6"	84°20'34"	✓	✓	✓	×	×	Highly Urban
28	02336152	9.04	33°48'37.6"	84°14'52.7"	✓	✓	✓	✓	✓	Urban
29	02336240	44.42	33°48'11.1"	84°20'26.5"	✓	✓	✓	✓	✓	Urban
30	02336300	139.69	33°49'13.1"	84°24'27.5"	✓	✓	✓	✓	✓	Highly Urban
31	02336313	4.36	33°49'17.9"	84°26'19.1"	✓	✓	✓	✓	✓	Highly Urban
32	02336340	28.65	33°53'51.9"	84°20'42.9"	✓	✓	✓	✓	✓	Highly Urban
33	02336360	42.81	33°52'09"	84°22'44"	✓	✓	✓	✓	✓	Urban
34	02336410	60.67	33°50'17.6"	84°26'21.4"	✓	✓	✓	✓	✓	Urban
35	02336526	21.57	33°47'40.1"	84°28'27.1"	✓	✓	✓	✓	✓	Highly Urban
36	02336728	54.56	33°44'36.7"	84°34'05.4"	✓	✓	✓	✓	✓	Rural
37	02337410	107.02	33°39'13.7"	84°49'15.7"	✓	✓	✓	✓	✓	Highly Rural
38	023362095	5.25	33°49'17"	84°16'29"	✓	✓	✓	×	×	Neutral