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URBANIZATION AND WATER QUALITY IN RURAL TENNESSEE, USA

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Three watersheds in the Cookeville, Tennessee area were selected to conduct a chemical and biological assessment of watershed water quality. Streams of 1st, 2nd and 3rd order were chosen to compare the effect of urbanization. Chloride, nitrate, sulfate, and phosphate were determined in water samples, and macroinvertebrate samples were collected. Results show higher levels of dissolved oxygen, total dissolved solids, nitrate and chloride were found in urban areas. Sulfate was found in all 1st order streams suggesting that this naturally occurring element may play a role in water quality. Sulfate is probably derived from geologic sources. Analysis of variance showed that three watersheds had different water quality in terms of dissolved oxygen, turbidity, chloride and nitrate. The biotic index score (BIS), integrated from individual macroinvertebrate BIS numbers, shows a negative correlation with turbidity, nitrate, chloride and a positive correlation with dissolved oxygen. Compared to EPA nutrient regional measurements, turbidity, sulfate, nitrogen, and conductivity found in the watersheds are much higher suggesting that water quality does not meet current ambient water quality standards. Percent oligochaetes and chironomids (%OC) and percent EPT were found to have positive and negative correlation respectively with percent urban area.

INTRODUCTION

During a previous study (Li et al., 2006) we investigated water quality in three watersheds surrounding the Cookeville, Tennessee area. We found there were differences in terms of macroinvertebrate community, and land use patterns. In this study, in addition to a biological assessment, more in-depth study of the selected watersheds was conducted and a chemical assessment of the targeted watersheds was performed to further evaluate the impact of land use on water quality. Part I of the project employed ion chromatography to identify pollutants including chloride, nitrate, sulfate and phosphates. Part II of the study focused on the macroinvertebrate community and diversity. The results were used to verify impact of urban development on water quality in the targeted watersheds.

STUDY AREA

Three watersheds, Pigeon Roost, Blackburn and Spring Creek, were chosen based on their proximity, size and characteristics. Figure 1 shows the sampling points from three watersheds. The map shows stream orders in different colors. Green, orange and red represent 1st, 2nd and 3rd orders respectively. Blue lines on the map are stream lines from the National Hydrography Dataset (USGS, 2006). The unconnected stream lines in the Pigeon Roost Watershed show the influence of karst geology. Pigeon Roost is an urban watershed where the City of Cookeville is located. The city has a population of 24,159 in 2000 (www.census.gov). Spring creek is listed as a reference stream by the Tennessee Department of Environment and Conservation. Blackburn is a suburban basin adjacent to Pigeon Roost. Residents in Blackburn still mostly engage in agriculture activities. Table 1 shows the basic parameters of watersheds in the study. Spring Creek is the largest watershed in terms of area. However, the highest drainage density was found in Pigeon Roost. More land clearing generally produces a higher drainage density (Marsh, 1997). Pigeon Roost is the most urbanized area of the three watersheds.

Three first-order, two second-order and two third-order stream points in each watershed were identified for this study (Figure 1). A total of 21 sampling points are used to collect water samples. Field and lab analyses provided chemical and biological data for further statistical analysis.

LAND USE/LAND COVER

The United State Geological Survey has provided an interactive map service for the public to view and download various land surface data. A recent data layer of land use was downloaded from http://seamless.usgs.gov. Several GIS procedures were performed to obtain clipped layers of three watersheds. The land use codes were then integrated to obtain percentage of three major categories of land use and land cover, as shown in Table 2 and Figure 2.

It is obvious that Pigeon Roost can be classified as an urban watershed due to its high percentage of urban area (76%). Fifty-nine percent of the Blackburn watershed is dominated by agriculture area while Spring Creek watershed has highest forest area within its boundary, at 51.67%.

Table 1. Watershed characteristics – drainage density of three watersheds.

Watershed	Area (mi^2)	Stream Length (mi)	Drainage Density (1/mi)
Pigeon Roost	16.86	23.60	1.40
Blackburn	21.86	20.02	0.92
Spring Creek	27.11	34.39	1.27

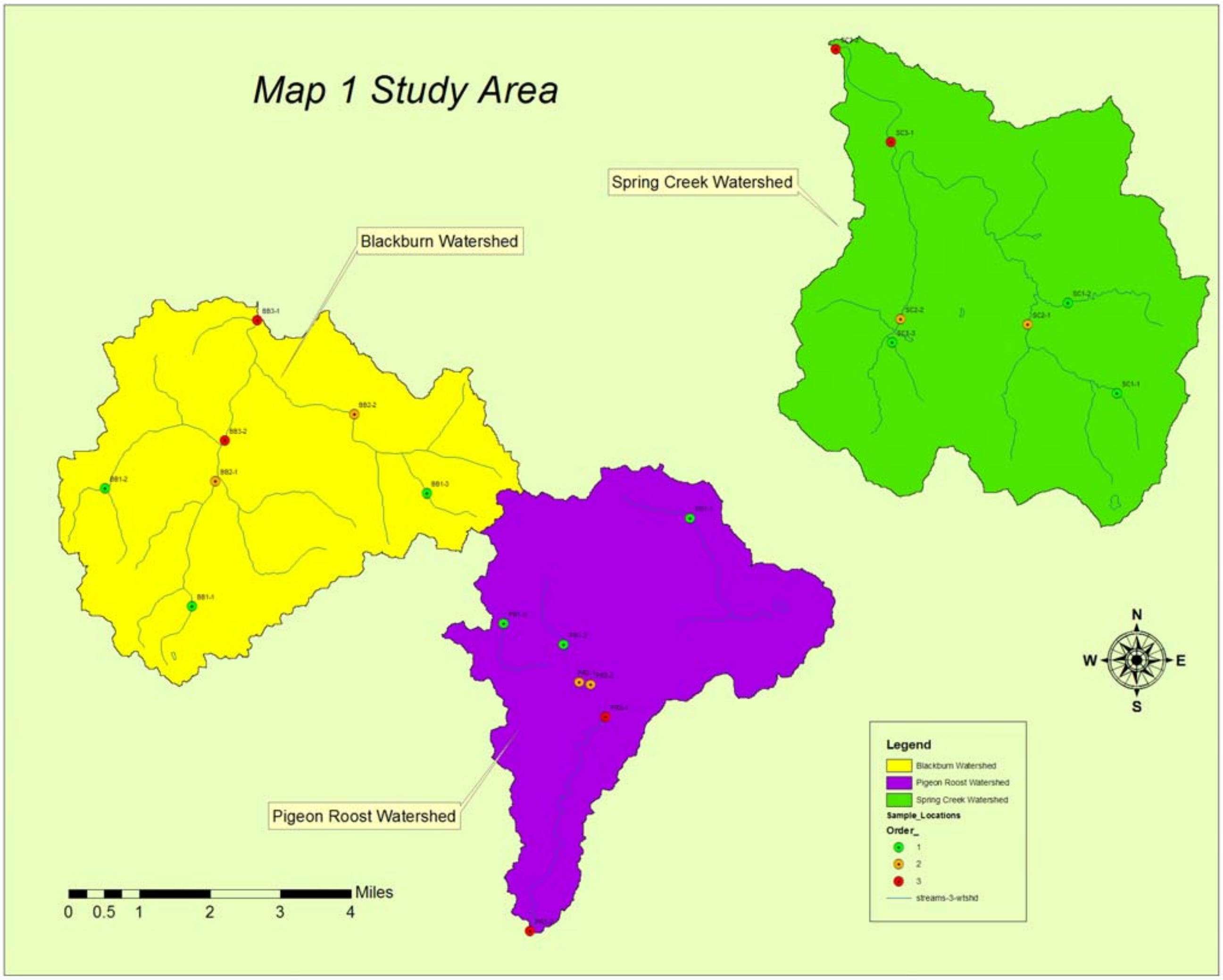

Figure 1. Study area.

Figure 2 shows land use patterns found in the watersheds. Pigeon Roost, at the center of the map, shows more red/pink colors than others.

Further divided sub-watersheds based on 21 sampling locations were obtained using GIS processes. Table 3 shows the percentage land use patterns in 21 sub-watersheds. It is evident that the percent land use patterns of sub-watersheds follow those of the parent watersheds.

METHODOLOGY/INSTRUMENTATION

As mentioned in previous section, GIS data layers were used to provide land use land cover data over the study area. Other information, such as stream layers, are incorporated into the GIS project to show locations of stream orders and stream networks for this study.

Table 2. Land use and land cover percentage for three watersheds.

Watershed	Forest (%)	Agriculture (%)	Urban (%)	Other (%)
Pigeon Roost (PR)	16.14	6.84	**76.27**	0.27
Blackburn (BB)	19.21	**59.24**	20.87	0.68
Spring Creek (SC)	**51.67**	37.30	8.92	2.11

Bold numbers indicate dominant land cover.

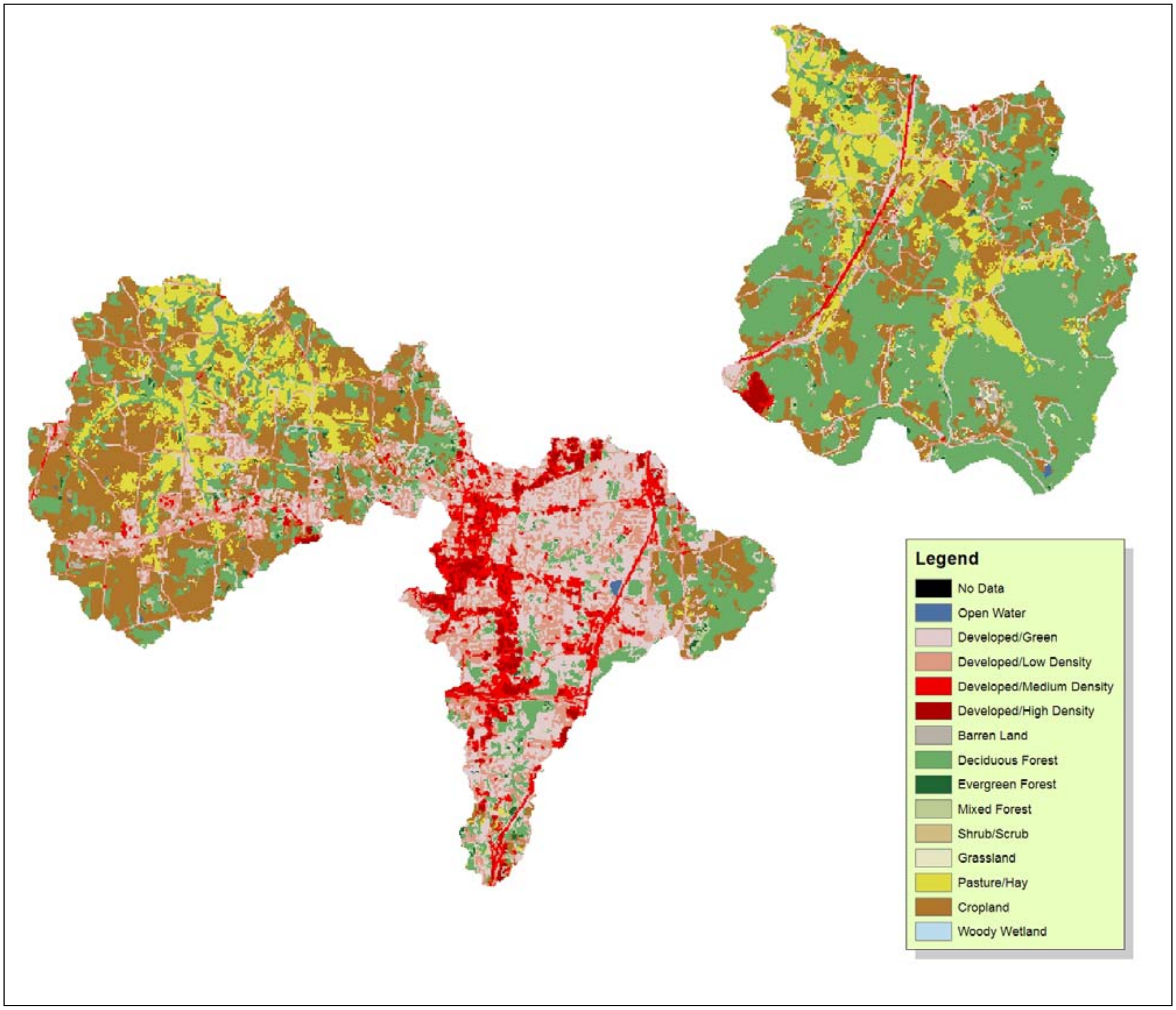

Figure 2. Land use cover - three different watersheds.

Field data, such as water temperature, velocity, flow rates, and total dissolved solids were measured and recorded for reference purposes. Water samples were taken from 21 sampling sites for chemical analysis for nitrate, sulfate and chloride. In the lab, water samples were measured to obtain pH and then filtered to remove bacteria for chemical analysis and to preserve the integrity of the samples. Standards of chloride, nitrate and sulfate were prepared for 1, 10 and 20 mg/L. Auto-calibration processes were performed before running filtered samples.

Table 3. Land use percentage in 21 sub-watersheds.

ID	Forest	Agr	Urban	ID	Forest	Agr	Urban	ID	Forest	Agr	Urban
BB1-1	23.95	65.57	9.33	SC1-1	87.65	7.72	1.62	PR1-1	6.32	0	93.56
BB1-2	20.32	68.96	9.49	SC1-2	65.28	26.90	4.81	PR1-2	0.93	0.43	98.64
BB1-3	18.79	16.83	62.37	SC1-3	64.29	30.26	3.60	PR1-3	0	0	99.10
BB2-1	20.48	69.77	9.06	SC2-1	73.23	17.73	5.69	PR2-1	1.82	0.31	97.61
BB2-2	23.11	44.83	31.86	SC2-2	57.55	28.22	12.28	PR2-2	19	11.59	68.30
BB3-1	19.21	59.24	20.87	SC3-1	54.23	34.53	8.96	PR3-1	14.64	7.91	76.58
BB3-2	14.40	59.90	21.80	SC3-2	51.67	37.30	8.92	PR3-2	16.14	6.84	76.27

BB : Blackburn, SC: Spring Creek, PR: Pigeon Roost

Macroinvertebrate samples were collected from three 3rd order streams from each watershed. In addition, two biological samples were collected at 2nd and 1st order streams in the Blackburn watershed. All samples were collected at riffle habitats since this provides the best habitat for most stream-dwelling macroinvertebrates. According to a study by Parsons and Norris (1996), sampling from similar habitats is a required procedure when comparing water quality among different watersheds. Procedures for collection and sampling techniques were described in a previous study (Li et al., 2006). Detailed information about macroinvertebrate identification can be found in the literature (Li et al., 2006; TDEC, 2002)

DATA ANALYSIS OF CONSTITUENTS

Table 4 shows analytical results of nitrate, sulfate and chloride from 21 sampling points. The shaded cells represent highest values of constituents found in each parent watershed. Highest chloride was found in PR1-3, where the water channel is surrounded by impervious road in the city area. A huge parking lot for a commercial plaza is next to the sampling location. The sampling location is a highly urbanized area. Runoff at this point is mainly from urban and impervious surfaces. Except for PR1-1, chloride levels found in other locations in Pigeon Roost are higher than 10 mg/l. The average chloride concentrations in the other two watersheds are lower than that found in Pigeon Roost.

Figure 3 shows the average, minimum and maximum values of chloride found in three parent watersheds, from a total of 21 sub-watersheds. It is evident that Pigeon Roost had the highest average at 23.53 mg/l while its maximum value of 53.74 mg/l is very high. Spring Creek is a

Table 4. Nitrate, sulfate and chloride values.

Blackburn	Nitrate	Sulfate	Chloride
BB1-1	0.26	4.62	2.05
BB1-2	0.56	7.32	7.93
BB1-3	2.48	11.98	15.06
BB2-1	3.32	5.95	6.69
BB2-2	6.76	10.52	32.09
BB3-1	3.55	6.95	12.89
BB3-2	3.36	6.41	7.66
Spring Creek	Nitrate	Sulfate	Chloride
SC1-1	3.07	6.90	6.02
SC1-2	3.74	6.83	5.11
SC1-3	5.76	15.03	13.50
SC2-1	2.16	7.61	1.91
SC2-2	5.00	14.31	11.12
SC3-1	2.75	8.38	4.08
SC3-2	2.82	8.55	5.09
Pigeon Roost	Nitrate	Sulfate	Chloride
PR1-1	2.88	5.62	4.77
PR1-2	3.64	12.36	21.43
PR1-3	10.77	19.01	53.77
PR2-1	5.20	7.50	15.61
PR2-2	4.34	8.51	13.60
PR3-1	4.94	6.82	21.47
PR3-2	20.22	13.03	34.07

reference stream for EPA and Tennessee Department of Environment and Conservation. The chloride range, compared to other two watersheds, is small. A similar trend was found in Figure 4, and in Figure 5 for nitrate and sulfate. In Figure 4, the average nitrate concentration of Pigeon Roost is two times higher than that found in the other two watersheds. The highest concentration of sulfate was found in the Pigeon Roost watershed while samples from Blackburn are the lowest of the three.

Turbidity, dissolved oxygen and total dissolved solids were also measured and are presented in the following tables.

a. Analysis of Variance - ANOVA

To test the differences in water quality between three watersheds, we used analysis of variance (ANOVA). ANOVA can provide immediate verification of differences between three or more watersheds. The values from 21 sampling points from three watersheds were used to test the null hypothesis; m1 = m2 = m3, which states that there is no difference in means of constituents from three watersheds. Table 5 shows the results. The null hypotheses of equal means from three watersheds for chloride, nitrate, dissolved oxygen, and turbidity are rejected based on the *F* ratio, at the significance level of α =0.05. The results indicate that higher concentrations of nitrate, chloride, turbidity and lower dissolved oxygen found in Pigeon Roost are supported statistically by ANOVA. Again, the result suggests the influence of urbanization on water quality, which will be demonstrated later in the study.

b. Land Use and Chloride

Land use and land cover have been major factors in the occurrence of phosphate and other pollutants (Osborne and Wiley, 1988). The results from their study indicate that urbanization is the major factor contributing soluble reactive phosphorus concentrations in the streams. To prove the correlation between urbanization and concentrations of constituents, we use regression analysis and *t* statistics in this study. All measurements of constituents were plotted against the urbanization ratio of contributing sub-watersheds. A regression line was established between controlling factors, urbanized ratio, and levels of constituents. Statistics was used to verify the trend is statistically correlated.

First, we looked at the correlation between chlorine and urbanization. Figure 6 presents the regression line of these two variables. The regression line produces a r^2 of 0.3716 which in turn, has a r value of 0.6096. We use the t statistics formula of

$$t_{(n-2)} = \frac{r}{\sqrt{\frac{(1-r^2)}{(n-2)}}} \qquad (1)$$

Table 5. Results of ANOVA.

	Variance			F Critical Value	
Constituents	Between	Within	F Ratio	at α=0.05	Test Decision
D.O.	5.55	0.01	385	3.55	Reject Ho
Turbidity	310.35	83.77	3.7	3.55	Reject Ho
TDS	18165	64170	3.53	3.55	Failed to reject Ho
Chloride	518.2	123.64	4.19	3.55	Reject Ho
Sulfate	27.78	13.71	2.03	3.55	Failed to reject Ho
Nitrate	82.88	14.96	5.54	3.55	Reject Ho

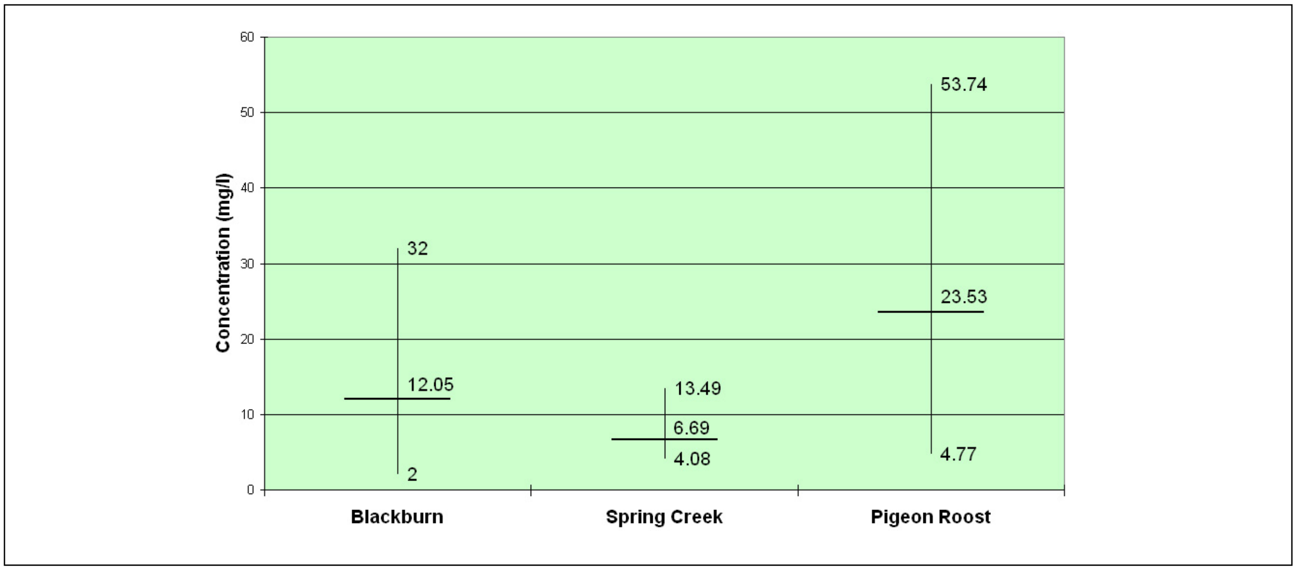

Figure 3. Average/Min/Max chloride concentrations.

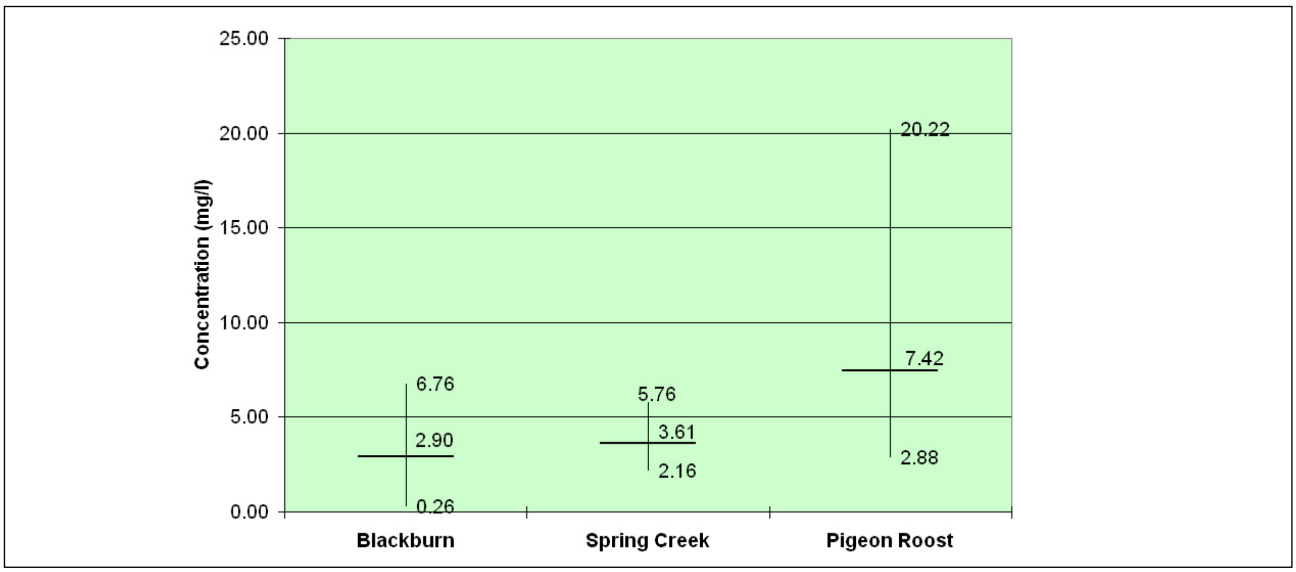

Figure 4. Average/Max/Min nitrate concentration.

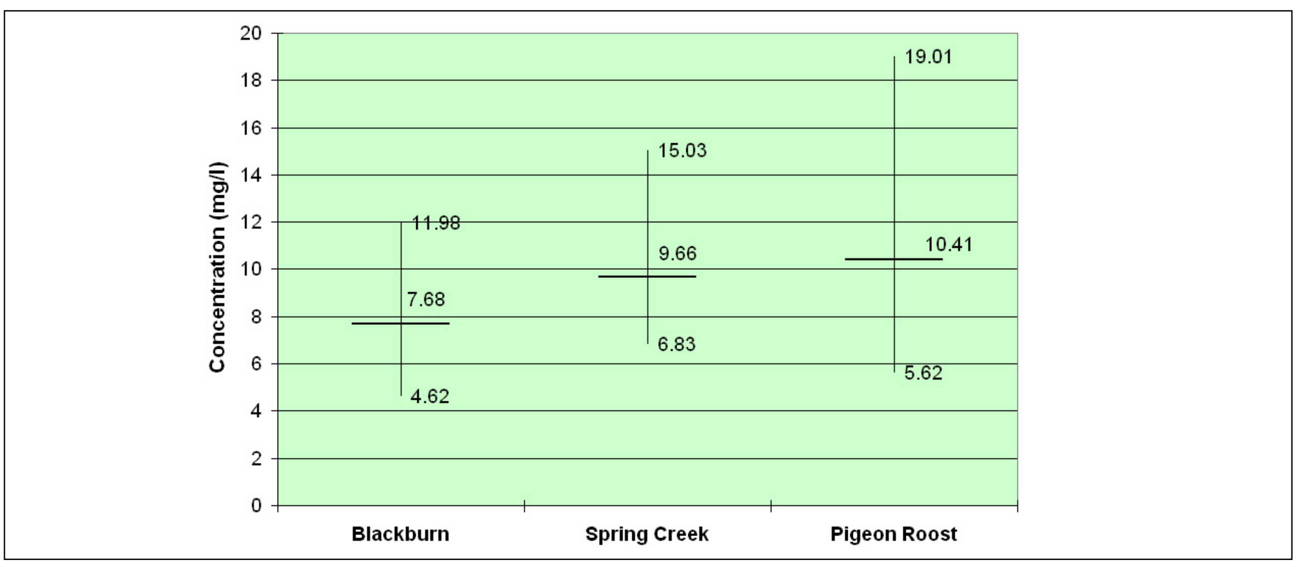

Figure 5. Average/Min/Max sulfate concentrations.

Computing $t_{(21-2)}$ gives 3.35 for this correlation, which is higher than the t_{19} statistics of 2.09 at α= 0.005 (two-tailed significance level). This shows that the correlation between chloride concentration and urbanization is valid statistically. Similarly, other indicators of pollution were determined using the same techniques. Table 6 shows the results and *t* statistics. Nitrate, TDS and D.O. are tested to prove that the correlation between these parameters and urbanization is valid. It indicates that more urbanized watersheds have higher pollution and lower D.O.

Table 6. Correlation coefficient and *t* statistics.

Constituent	R^2	R	Trend	t-Statistics	Significance	α
Chloride	0.3716	0.6096	Positive	3.35	Yes	0.005
Sulfate	0.0960	0.3098	Positive	1.420	No	
Nitrate	0.1754	0.4188	Positive	2.010	Yes	0.05
TDS	0.3102	0.5570	Positive	2.923	Yes	0.005
Turbidity	0.0004	0.0200	None	0.087	No	
D.O.	0.5419	0.7361	Negative	4.741	Yes	0.005

c. Macroinvertebrate Water Quality Indicators

Macroinvertebrate samples were collected from three parent watersheds in this study. Previous year, macroinvertebrate data were collected at three 3rd order streams (Li et al., 2006). This year, the study was expanded to cover two samples from first and second order streams of the Blackburn watershed. Crunkilton and Duchrow's (Crunkilton and Duchrow, 1991) findings suggested highest densities of macroinvertebrate community were found in intermediate order streams. In this study, we will focus on the difference between stream order and watersheds in their biological indicators, such as BIS scores, %OC or %EPT.

Table 7 presents a detailed analytical table and computational method used to obtain values for NCBI (North Carolina Biotic Index). The NCBI value is lower in 2006 than in 2005. However, the number of clingers (a good water quality indicator) was found higher in 2006.

The difference is insignificant and does not raise any concern. Tables 8 and 9 present similar results for Spring Creek and Pigeon Roost watersheds at 3rd order streams.

In Table 7, the number of clingers found in 2005 and 2006 are almost identical. The NCBI values found in these two years are very close also. The water quality seems to remain the same. There is no major anthropogenic modification inside of watershed except for a few houses. The majority

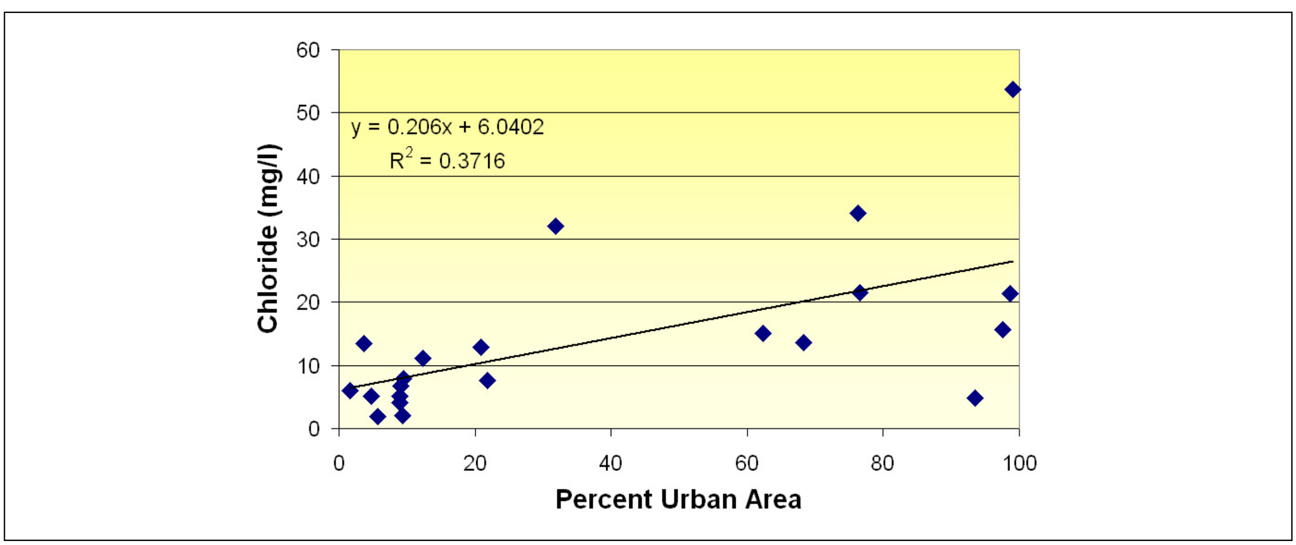

Figure 6. Chloride vs urbanization.

of land is still used for agriculture purposes. Eighty-three *Stenonema* were found at the sampling site of the Blackburn stream. This is an indicator of good water quality. Table 9 shows a high number of *Stenonema* found in the stream. More *Isonychia* was found in the stream. However, this is not a clinger. The total NCBI value is higher in 2006, compared to 2005 with the fact that more clingers were found in 2005. Pigeon Roost has high number of two species which add up to a high value of total NCBI. However, the diversity of macroinvertebrate is limited in the stream.

Two other processes of identification from 1st and 2nd order streams of Blackburn were performed and compared in Table 10.

After computing these values, they were equalized by assigning a score of 0, 2, 4, or 6 based on Tennessee's ecoregion reference database for bioregion 71g (Table 10). The values of each watershed then add up to a value and are then assigned an Bioregion Index Score (BIS) rating using the bioregion index scores chart.

Use of EPT (Ephemeroptera, Placeptera, and Trichoptera) for evaluating water quality in the United States dates back to Richardson in 1928 studies of the Illinois River (Goodnight, 1973). Due to its simple and stable process, Wallace et al. (1996) endorsed use of EPT for tracking changes and comparison in water quality.

The 1st order stream in Blackburn is a small creek originated in a farming area. An EPT score of 2 was found in the sampling location, while the 2nd and the 3rd streams presented higher EPT scores. The state-reference site, Spring Creek, has a score of 4. An EPT score of 0 was found in Pigeon Roost's 3rd order stream. This is a very alarming sign for a developing small urban watershed. Lower than 50% of EPT were found in BB1 and PR3. The NCBI value of Pigeon Roost's 3rd order stream is evaluated at 0, compared to 4 or above for other streams. BIS scores from two

Table 7. Results of macroinvertebrate identification in Blackburn 3rd order stream.

Order	Family	Genus	#	NCBI Value	NCBI	Clingers
Diptera	*Typulidae*	*Typula*	3	7.33	21.99	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche*	21	6.22	130.62	21
Ephemeroptera	*Isonychidae*	*Isonychia*	31	3.45	106.95	
Plecoptera	*Perlodidae*	*Isoperla*	8	1.5	12	8
Ephemeroptera	*Heptogeniidae*	*Stenonema*	83	3.45	286.35	83
Coleoptera	*Elmidae*	*Optioservus*	21	2.36	49.56	21
Diptera	*Athericidae*	*Atherix*	7	2	14	
Plecoptera	*Iaeniopterygidae*	*Taeniopteryx*	10	5.37	53.7	
Diptera	*Simulidae*	*Simulium*	3	4	12	3
Coleoptera	*Psephenidae*	*Psephenus*	12	2.35	28.2	12
Ephemeroptera	*Baetidae*	*Acentrella*	1	2.6	2.6	
Decapoda	*Cambaridae*	*Orconectes*	3	2.6	7.8	
Trichoptera	*Philopotanidae*	*Chimarra*	9	2.76	24.84	9
Plecoptera	*Luctridae*	*Leuctra*	1	0.67	0.67	1
Odonata	*Gomphidae*	*Gomphus*	1	5.8	5.8	
Trichoptera	*Hydropsychidae*	*Hydropsyche*	2	4.3	8.6	2
Megaloptera	*Corydalidae*	*Nigronia*	1	5.25	5.25	1
Trichoptera	*Glossosomatidae*	*Glossosoma*	3	1.55	4.65	3
Diptera	*Chironomidae*	*Polypedilum*	4	5.69	22.76	
Diptera	*Chironomidae*	*Eukiefferiella*	2	3.43	6.86	
		Total (2006)	226		805.2	164
		Total (2005)	219		905.9	163

NCBI : North Carolina Biotic Index Scores. Clingers: organisms that can "hold their place" on bottom substrates in motion. More clingers means better water quality.

Table 8. Results of macroinvertebrate identification in Spring Creek 3rd order stream.

Order	Family	Genus	Number	NCBI value	NCBI	Clingers
Ephemeroptera	*Heptageniidae*	*Stenonema*	45	3.45	155.25	45
Ephemeroptera	*Isonychidae*	*Isonychia*	72	3.45	248.4	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche*	33	6.22	205.26	33
Trichoptera	*Hydropsychidae*	*Hydropsyche*	3	4.3	12.9	3
Diptera	*Athericidae*	*Atherix*	7	2	14	
Coleoptera	*Psephenidae*	*Psephenus*	2	2.35	4.7	2
Ephemeroptera	*Baetidae*	*Baetis*	8	4.51	36.08	
Megaloptera	*Corydalidae*	*Corydalus*	1	5.16	5.16	1
Megaloptera	*Corydalidae*	*Nigronia*	1	5.25	5.25	1
Diptera	*Typulidae*	*Typula*	1	7.33	7.33	
Ephemeroptera	*Baetidae*	*Acentrella*	6	3.6	21.6	
Trichoptera	*Philopotanidae*	*Chimarra*	1	2.76	2.76	1
Coleoptera	*Elmidae*	*Optioservus*	3	2.36	7.08	3
Diptera	*Simulidae*	*Simulium*	1	4	4	1
Ephemeroptera	*Caenidae*	*Caenis*	1	7.41	7.41	
Diptera	*Chironomidae*	*Polypedilum*	39	5.69	221.91	
Diptera	*Chironomidae*	*Conchapelopia*	1	4.5	4.5	
		Total (2006)	225		963.59	90
		Total (2005)	172		653.05	117

NCBI : North Carolina Biotic Index Scores. Clingers: organisms that can "hold their place" on bottom substrates in motion. More clingers means better water quality.

Table 9. Results of macroinvertebrate identification in Pigeon Roost 3rd order stream.

Order	Family	Genus	Number	NCBI value	NCBI	Clingers
Trichoptera	*Hydropsychidae*	*Cheumatopsyche*	78	6.22	485.16	78
Plecoptera	*Chloroperlidae*	*Haploperla*	1	0.98	0.98	1
Lumbriculida	*Lumbriculidae*	*Lumbriculus*	6	7.03	42.18	
Diptera	*Chironomidae*	*Microtendipes*	81	5.53	447.93	81
Diptera	*Chironomidae*	*Polypedilum*	8	5.69	45.52	
Diptera	*Chironomidae*	*Chironomus*	18	9.63	173.34	
Diptera	*Chironomidae*	*Conchapelopia*	2	4.5	9	
		Total (2006)	194		1204.11	160
		Total (2005)	183		901.22	83

NCBI : North Carolina Biotic Index Scores. Clingers: organisms that can "hold their place" on bottom substrates in motion. More clingers means better water quality.

years (2005 and 2006) were listed and compared in Table 11. The 3rd order streams from Pigeon Roost and Spring Creek show lower BIS scores in 2006 than those in 2005. The difference may not be significant enough to draw any statistical conclusion. However, the consistent lower BIS scores in Pigeon Roost may be due to urbanization or point source pollution in the upper stream area.

d. Chemical and Biological Indicators

The correction between BIS and the chemical constituents, TDS, turbidity, sulfate, chloride, nitrate and dissolved oxygen, were studied and listed in Table 12.

BIS has a positive correlation with D.O. while negative correlations were found for turbidity, chloride, and nitrate. More studies will be required to draw strong conclusions from similar observations and field data.

Table 10. Biocriteria table (TDEC, 2002).

Target Index Score				
Metric	6 (Non)	4 (Slight)	2 (Moderate)	0 (Severe)
Taxa Richness	> 27	19 – 27	10 -18	< 10
EPT Richness	> 9	7 – 9	4 -6	
% EPT	> 53.38	35.9 – 53.37	13- 35.8	< 18
% OC	< 27.5	27.5 – 51.6	51.7 – 75.8	> 75.8
NCBI	< 4.74	4.74 – 6.49	6.5 – 8.25	> 8.25
% Dominant	< 36.7	36.7 – 57.7	57.7 – 78.8	> 78.8
% Clingers	> 52.4	35.0 – 52.4	17.5 – 34.9	< 17.5

Taxa Richness (TR) - this is the total number of distinct taxa (genera) found in the subsample.

EPT Richness (Ephemeroptera Plecoptera Trichoptera) - this is the total number of genera found in the orders Ephemeroptera, Plecoptera, and Trichoptera.

% EPT – (Number of Ephemeroptera + Plecoptera + Trichoptera X 100)/Total Number of individuals.

% OC (percent of oligochaetes and chironomids) = (Total number of Oligochaeta + Chironomidae X 100) /Total number of individuals

NCBI (North Carolina Biotic Index)

NCBI = $S(X_i * T_i)/N$ where X_i=number of individuals in a taxon, T_i=tolerance value of a taxon, N=total number of individuals.

% Dominant (percent contribution of the single most dominant taxon) = Total individuals in the most dominant taxon X 100 / Total number of individuals

% Clingers = Total number of clinger individuals X 100 / Total individuals

Clingers are the organisms that build fixed homes or have adaptations to attach to surfaces in flowing water. Clingers usually indicate good water quality.

Table 11. TR, EPT, % EPT, %OC, % Dominant, %Clingers and BIS scores.

	BB1	score	BB2	score	BB3	score	SC3	score	PR3	score
Taxa Richness (TR)	13	2	20	4	20	4	17	2	7	0
EPT Richness (EPT)	4	2	11	6	10	6	8	4	1	0
% EPT	36.21	4	82.67	6	74.78	6	75.11	6	40.21	4
% OC	4.31	6	2.22	6	2.65	6	17.77	6	59.28	2
NCBI	3.1	6	3.8	6	3.56	6	4.28	4	82.47	0
% Dominant	42.24	4	40.44	4	36.73	4	32	6	41.75	4
% Clingers	90.52	6	70.22	6	72.57	6	40	4	82.47	6
BIS Score		30		38		38		32		16
2005 BIS Score						38		36		20

Table 12. BIS vs. chemical parameters and significance of correlation via *t* test.

	TDS	Turbidity	SO_4	Cl	NO_3	DO
BIS	-0.66	-0.83	-0.82	-0.85	-0.85	0.94
t	-1.74	-2.99	-2.86	-3.17	-3.29	5.51
Significant at α=0.05, t=2.92	No	Yes	No	Yes	Yes	Yes

e. Biological Indicators and Urbanization

Roy et al. (2003) suggested that a less diverse and more tolerant stream macroinvertebrate community could be the result of urbanization. In this study, we have a total of 5 sampling sites for macroinvertebrate identification and their biotic indicators. Out of 5 sites, two sites, BB1 and BB2 are sub-watersheds of BB3, the 3rd order stream sampling site. To compare urbanization ratio and biotic indicators at the same stream order, we use three 3rd order stream watersheds.

More than three-quarters of surface land in Pigeon Roost is covered by urban area. Spring Creek has the lowest urban ratio while 20% of the land in Blackburn is covered by urban area.

Figure 7 shows the relationship between % OC, %EPT and % urbanization for three watersheds. It is evident that while percent urban area increases, % EPT drops and %OC increases, showing that urbanization has a strong influence on macroinvertebrate community and diversity.

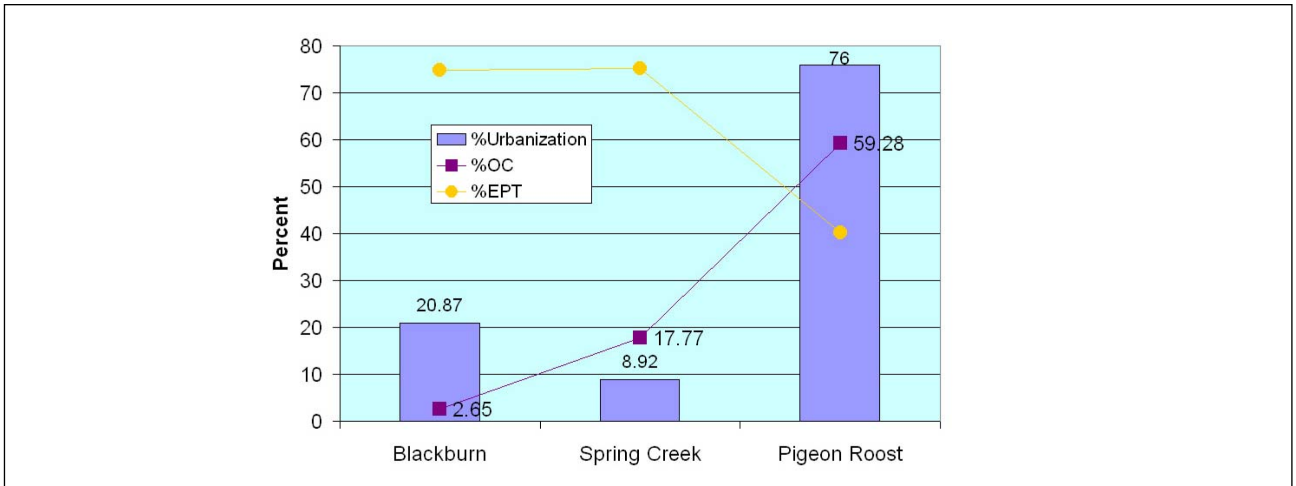

Figure 7. %OC, % EPT and % urbanization.

CONCLUSIONS

The study has shown that urbanization has a positive correlation with the levels of TDS, chloride, nitrate, and dissolved oxygen. ANOVA shows that the differences among watersheds in terms of nitrate, chloride, D.O. and turbidity were significant statistically. Chemically and biologically, Pigeon Roost, the most urbanized watershed, presented the lowest water quality based on this study. %EPT was found in reverse relationship with urbanization ratio. The study proved that, even in a rural county in Tennessee, urbanization processes can have important impacts on water quality.

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