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Assessing the Influence of Agricultural Nonpoint Source Pollution on Water Quality in Central Kentucky's Headwater Streams

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Abstract: This study addresses the pressing issue of nonpoint source water pollution in Kentucky, particularly associated with large-scale agriculture. Centered on the outer bluegrass region of Central Kentucky, the research examines the water quality of headwater streams during the agricultural season. The approach involves geospatial land cover classification using aerial imagery. Water quality data were collected during the agricultural growing season from May to October 2018. Land cover classification utilized ERDAS Imagine 2016 and ESRI ArcGIS 10.6 GIS software, while conventional water quality parameters were measured with a YSI ProDSS® multiparameter water probe and a Marsh-McBirney Flo-Mate 2000 flow meter. Statistical analyses show significant differences in stream water chemistry, suggesting the impact of agricultural nonpoint source pollution. Forested streams exhibited more varied conditions, indicating a potentially better environment. As agricultural land percentage increased, water chemistry variation suggested a measurable threshold for changes. Significant differences in water quality between agricultural and forested streams highlight the potential benefits of expanding riparian zones beyond regulations. Enlarging these zones is proposed as a strategy to mitigate nonpoint source pollution in Kentucky's waterways.

Keywords: agriculture; Kentucky; nonpoint source; water pollution; watershed quality

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1. Introduction

Nonpoint source (NPS) pollution is a global issue, posing a major threat to watershed health [1]. NPS is mainly concentrated in the secondary protection area, with a large population density and a large proportion of agricultural land [2]. Agricultural NPS is the most significant contributor to water pollution, exerting a substantial influence on the quality of water resources [3]. Agricultural runoff, arising from fertilizer use and intensive tillage, adversely affects local environments [4]. Excessive tillage leads to increased sediment/mineral loss, runoff, and decreased soil productivity [5]. This leads to the proliferation of invasive species like bush honeysuckle (*Lonicera maackii*) in riparian zones since they are more adaptive to grow in disturbed soils than native plants [6,7].

Farmers have also expanded fields into tree lines to increase production, limiting deep-rooted vegetation to fence rows and hillsides. Livestock can suppress vegetation growth when it has access to natural areas and riparian zones, which can negatively impact water quality [8,9]. The degradation of riparian zones intensifies runoff concerns, causing downstream flooding and aquatic life degradation through increasing levels of suspended solids (sediment) [10–12]. This has a tremendous impact on terrestrial and aquatic ecosystems [13]. While the agricultural inputs that degrade water quality are well recognized, their impact varies based on geologic and topographic factors [14].

1.1. Watershed Quality

Landscape changes due to agriculture and urban development in the U.S. have caused a 95% decline in natural state watershed surface area [15]. The interconnected nature of watershed segments amplifies environmental impact [16]. Land cover changes affect water balances uniquely in each watershed [17] due to the significant connections between watershed characteristics and water quality indicators linked to geology and land use [14,18]. Watershed-based management considers environmental, political, and socio-economic factors [19–21], covering public availability, sediment control, ecosystem conservation, and water quality [22,23]. This holistic approach transcends boundaries, offering the best opportunity for habitat conservation and community-based cooperation [24].

It is important to have good water quality to support healthy and diverse aquatic life, which can be negatively impacted by nonpoint source pollutants. Sampling water quality parameters such as pH, temperature, oxidation–reduction potential, conductivity, total suspended solids (TSS), total dissolved solids (TDS), and TSS discharge are great ways to determine the health of waterways [15]. An optimal pH is vital for freshwater organisms, while temperature influences solubility, gas levels, and dissolved oxygen concentration, posing thermal pollution risks at elevated temperatures. Dissolved oxygen monitoring ensures adequate concentrations, and oxidation–reduction potential stabilizes the pH. Conductivity measures electrical current capacity, and TSS reflects organic and inorganic materials influenced by watershed vegetation. Assessing TSS discharge provides insights into the human impact on water quality. TDS measures all dissolved substances, and elevated levels may indicate contamination. Understanding these parameters is key to preserving aquatic environments.

1.2. Kentucky's Water Resources and Agricultural Pollution

Kentucky's extensive water network, comprising over 92,000 miles of streams, 1000 square miles of wetlands, and 350 square miles of lakes, serves diverse ecosystem needs. These vital water resources, home to 75% of the state's endangered species, face challenges, as more than half of Kentucky's assessed waterways show some level of impairment [15]. Managing nonpoint source pollution, especially from large-scale agriculture, is challenging. Collaborative efforts involving federal, state, and university programs, like the Kentucky Department for Natural Resources (NRCS), the United States Department of Agriculture (USDA), and the Kentucky Water Resources Research Institute (KWRRI), aim to address pollution issues. Legislative measures, such as the Clean Water Act of 1972 and the Kentucky Agriculture Water Quality Act of 1994, underscore the commitment to combat water pollution. The Kentucky Nonpoint Source Program has actively supported watershed planning projects since 2004, leading to the approval of 27 EPA-accepted watershed plans [25].

Kentucky heavily relies on water resources for agriculture, with crop production exceeding USD 4.2 billion in 2017 [26]. Despite monitoring programs, there is a lack of comprehensive water quality data, particularly in first-order streams in upper watersheds. A spatial and temporal analysis at the stream headwater scale is needed [27,28], and advances in GIS programs and water quality sensor technology offer opportunities for precise data generation. Kentucky can leverage these technologies to enhance understanding and achieve conservation goals. One of the main waterways in Kentucky, the Kentucky River, has revealed water quality concerns, as it fell below state standards [3]. Unlike agriculture, forest management and timber harvesting have designed forestry best management practices (BMPs) to reduce nonpoint source pollutants on timber harvest sites that loggers follow to meet state guidelines or regulations and sustainable forestry initiative standards [29]. Forestry BMPs have been found to be very effective in reducing nonpoint source pollution and not impacting water quality during and after timber harvesting operations. Agriculture is lacking in regard to implementing similar practices as those performed in forestry, and research in comprehensive comparisons between water quality in agricultural and forested watershed areas is needed.

This study addressed the gap by analyzing water quality and land cover data in Central Kentucky's outer bluegrass region, focusing on chemical and biological trends in headwater streams. Objectives include geospatial land cover classification using National Agriculture Imagery Program (NAIP) aerial imagery and comparing water quality data from streams in agriculture-dominated and forested areas. This study investigated NPS, particularly agricultural runoff, to assess its impact on water quality. Beyond agriculture, it also emphasizes the role of forested watersheds in understanding water quality. Overall, this study aimed to support watershed management plans in Kentucky, assisting in resource allocation and identifying watersheds prone to poor water quality. The results can contribute to a review of national public policies, specifically addressing land use choices.

2. Materials and Methods

2.1. Study Area

The study area, illustrated in Figure 1, comprised two 10-digit Hydrologic Unit watersheds in Shelby and Henry counties within the outer bluegrass region of Central Kentucky. The Bullskin–Clear Creek watershed, mainly in Shelby county was characterized by predominantly agricultural land cover, while the Sixmile Creek watershed, primarily in Henry county, featured a high percentage of forested land. The former is referred to as the Agricultural (Ag) watershed, emphasizing row crops, hay fields, and livestock, with limited forested areas in riparian zones. In contrast, the forested watershed, the latter, showcased native deciduous and evergreen trees alongside invasive species like *Lonicera maacki* (bush honeysuckle) and *Rosa multiflora* (multiflora rose).

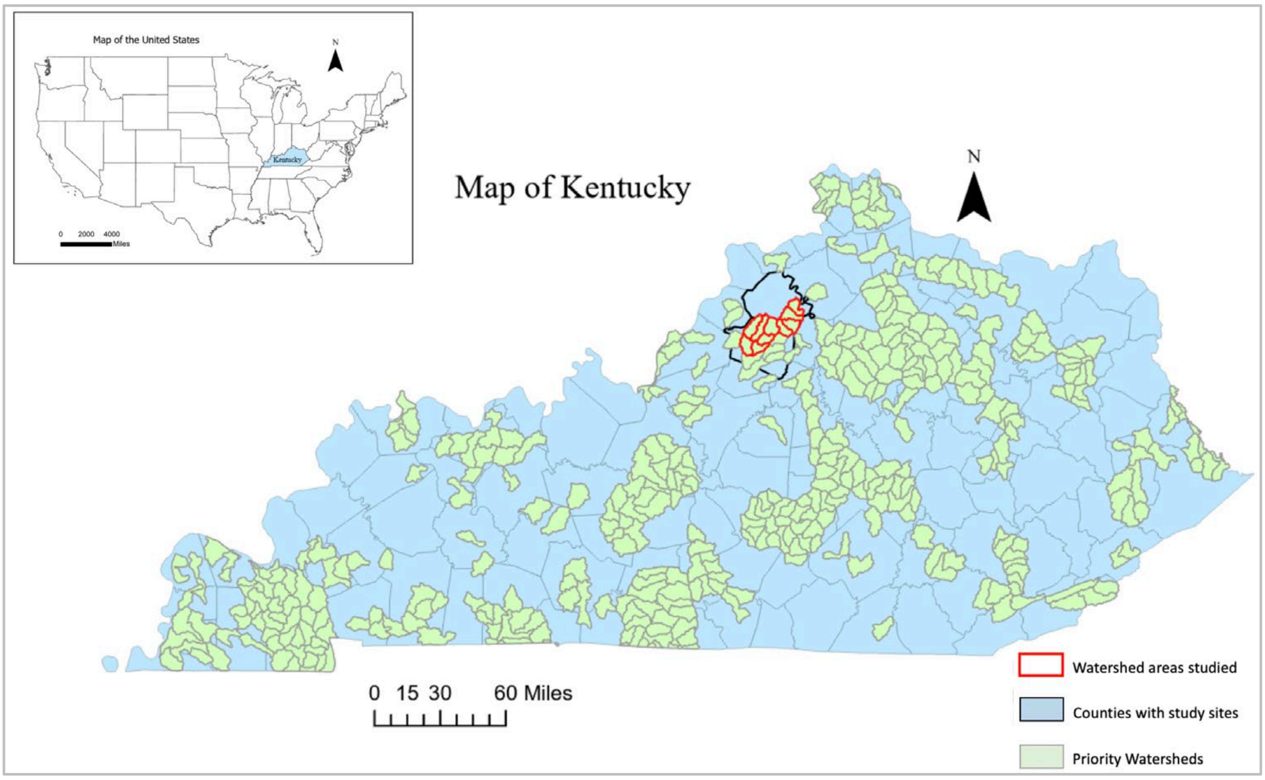


Figure 1. *Cont.*

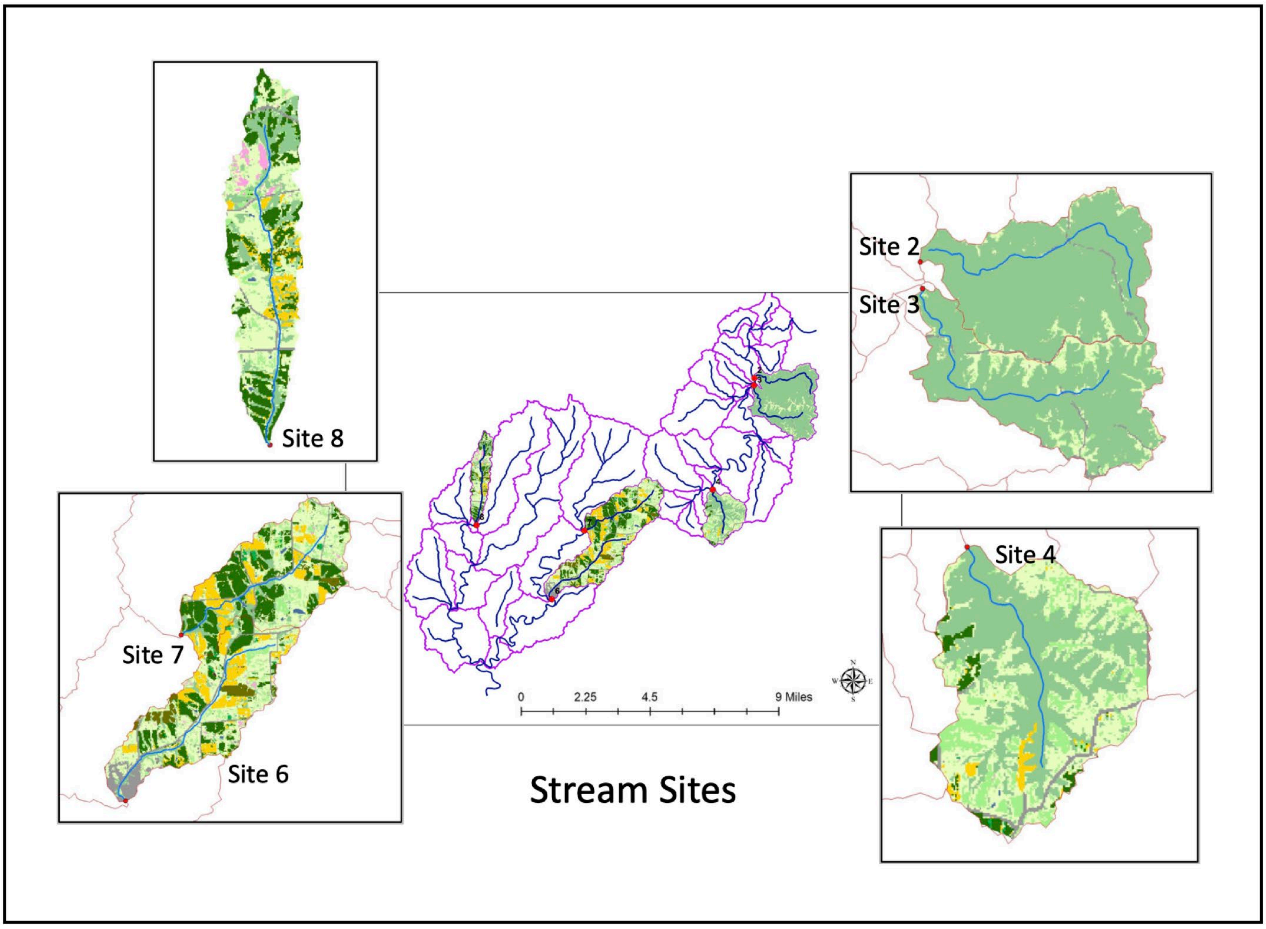


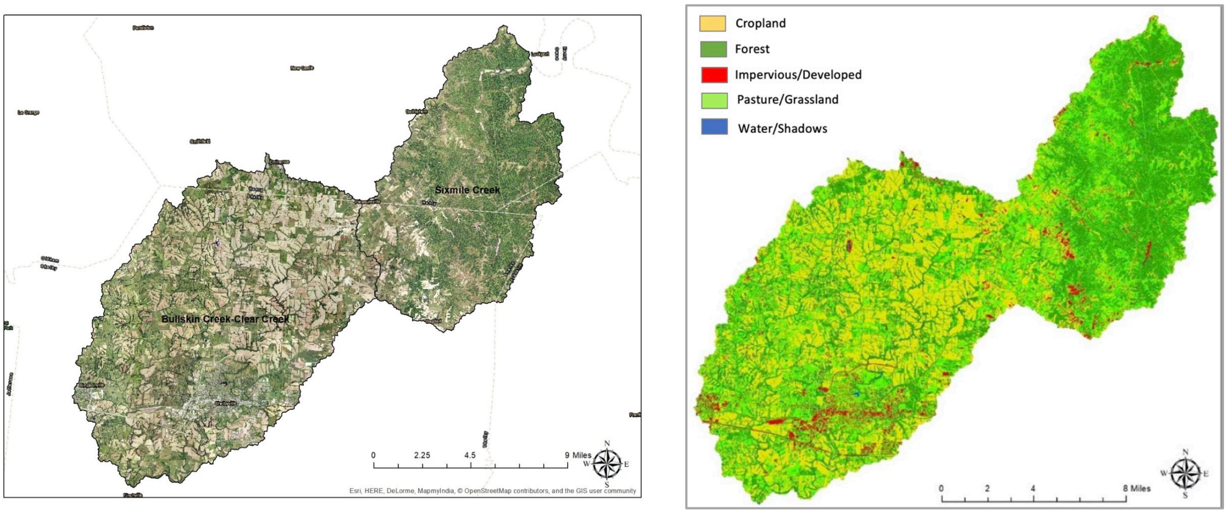
Figure 1. Study area showing six headwater stream sites sampled within watersheds across two counties in Kentucky.

2.2. Data Collection Protocol

For Objective 1, iso-unsupervised classification with five land cover classes and four-color Infrared (CIR) bands was employed using ESRI ArcMap 10.6 and ERDAS Imagine 2016 software. A basic accuracy assessment ensured the representativeness of land cover classes. USGS EarthExplorer online portal facilitated data download, obtaining high-res NAIP imagery from May 2016 for the study area. Mosaicking was performed using ERDAS Imagine 2016, and iso-unsupervised classification with red, blue, green, and near-infrared (NIR) bands in ESRI's ArcMap 10.6 identified five land cover classes. These classes—impervious/developed, cropland, pasture/grassland, forest, and water—were determined based on pixel color values. ERDAS Imagine's "calculate attribute statistics" feature aided in calculating class percentages for drainage areas and the two large watersheds. The vector data (watershed boundaries, stream flow lines, drainage areas, roads, and county boundaries) were obtained from KyGeoportal and clipped to the study area. Forested and Ag watershed boundaries were defined by HUC 10 watershed units, while HUC 14 units outlined drainage areas around each stream site. Crop information in Ag watershed fields was obtained from the USDA National Agricultural Statistics Service (NASS) cropland data viewer.

A natural color mosaic was created from USDA NAIP imagery, covering the entire study area, including both watersheds. USDA NAIP offers high-resolution aerial imagery captured during US growing seasons for environmental and agricultural uses [30]. The mosaic remains free from atmospheric interference, such as clouds, ensuring a clear view of the complete study area (Figure 2a). A classified raster of the entire study area was generated through the classification procedure and applied to the NAIP imagery mosaic (Figure 2b).

The classifications consisted of cropland, forest, impervious/developed, pasture/grassland, and water/shadows.



(**a**) (**b**)

Figure 2. (**a**) Mosaic of USDA NAIP. (**b**) Classified raster of the study area.

The workflow, illustrated in Figure 3, provides a clear step-by-step overview of the process.

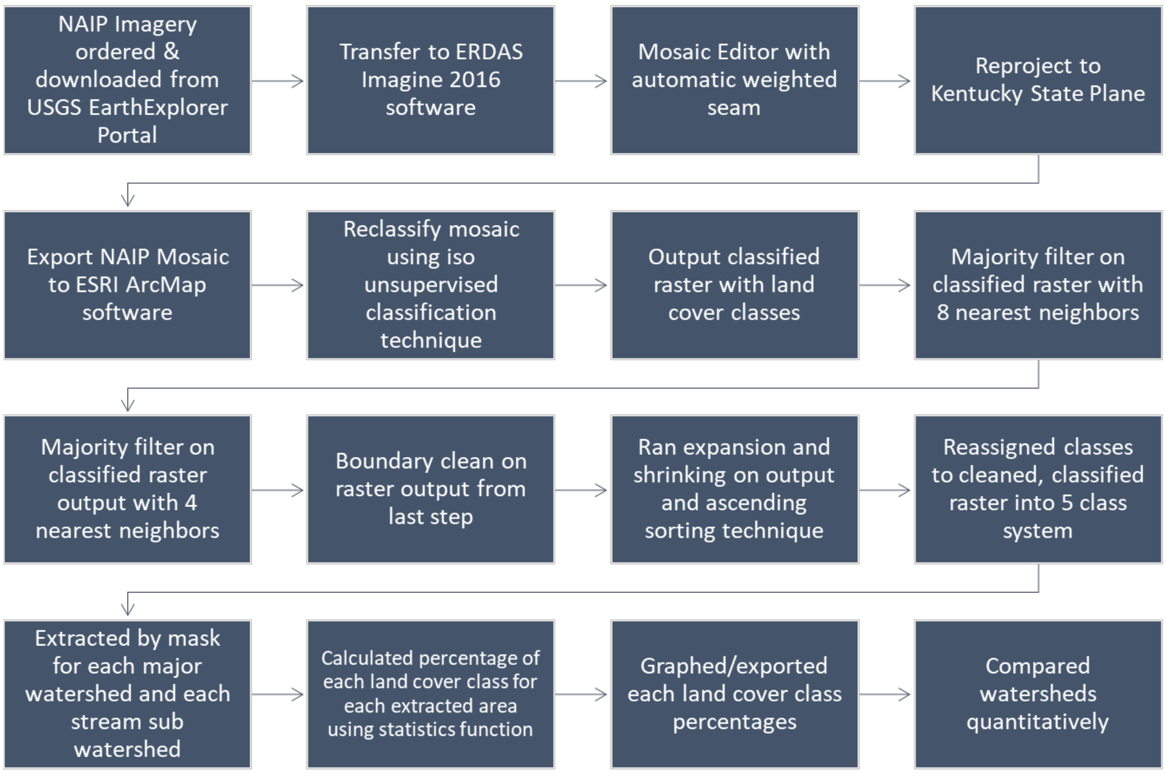


Figure 3. GIS workflow diagram.

For Objective 2, six headwater streams were selected: three in the agricultural watershed (Mulberry Creek, East Clear Creek, and Lutz Run Creek) and three in the forested watershed (Woodcocks Branch, Little Sixmile, and Indian Fork Creek), identified through Objective 1 results. Sampling occurred at each site three times per week (Monday, Wednesday, and Friday) over six months, from May to October 2018, covering the agricultural growing season. The sampling order between sites on each day was randomized using Excel 2016. A total of 463 measurements were taken, and each site was sampled approximately 74 times. Complete records for all stream sites were obtained on 75 out of 80 possible measurement days, resulting in a total of 466 measurements. Each stream had an average of 76 readings per month, contributing to a comprehensive dataset. Over the six-month period, the study area received 32.54 inches of precipitation, averaging 5.42 inches per month, according to the KY Mesonet weather station.

Water quality parameters were monitored using an EPA-approved YSI ProDSS® Multiparameter Sampling Instrument (YSI Incorporated, Yellow Springs, OH, USA) with GPS. Optical dissolved oxygen (ODO), pH, turbidity, and total suspended solids (TSS) were taken at each site in the center of the water flow. The ProDSS was programmed to read TSS concentrations through a lab-based calibration of the turbidity sensor. Grab samples from stream sites underwent a lab analysis based on the US EPA gravimetric TSS method. Stream flow was measured using a Marsh-McBirney Flo-Mate 2000 electromagnetic flow meter (McCrometer, Inc., Hemet, CA, USA), with velocity measurements taken at each stream transect. Intervals between velocity measurements were determined by the distance between effective flow edges. Measurements were taken every half foot for effective stream flows of ten feet or less and every foot for flows exceeding ten feet, extending from one effective flow edge to the other. Data were recorded manually and digitized into a standard flow sheet calculation template. TSS discharge was mathematically derived using the flow/velocity measurements and TSS concentration for each sample. Flow velocity data in cubic feet per second (cfs) were converted to liters per second (L/s). Then, the TSS concentration (mg/L) was multiplied by flow velocity (L/s) to derive the TSS discharge (mg/s). Precipitation data collected from the KY Mesonet Shelby County CROP station were used to monitor the number of days since the last significant precipitation event during each sampling day.

2.3. Data Analysis

For land cover classification, percentages of land cover classes were calculated within the boundaries of the two Hydrologic Unit Code (HUC), ten watersheds, and the drainage areas of the six streams (HUC 14 units). Each stream's drainage area was individually clipped, and land cover percentages were extracted to assess distribution within and between drainage areas. The statistical software used was SAS-JMP Version 15.0.0 [31]. One-way ANOVA tests were conducted to identify significant differences in water quality parameters between forest and agricultural stream sites. Two-way ANOVA tests were conducted to see if there was a difference between season (spring, summer, and fall) and forest and agricultural stream sites. When the ANOVA models were significant, Fisher's Least Significant Difference (LSD) was used for multiple comparison tests. Pearson's correlation analysis was performed to examine the interactions between each set of parameter values. An alpha level of 0.05 was used for all tests.

3. Results

A classified raster was created for each HUC 14 watershed to delineate and characterize land cover classes within each watershed (Figure 4). The classified raster for each stream site was extracted by mask from the overall study area raster, with separate calculations for land class percentages. Sites 2, 3, and 4 (Woodcocks Branch, Little Sixmile Creek, and Indian Fork Creek, respectively) are in the Forested watershed (predominantly forest cover), while Sites 6, 7, and 8 (Mulberry Creek, East Clear Creek, and Lutz Run Creek, respectively) are in the agriculture watershed (agricultural land use predominates).

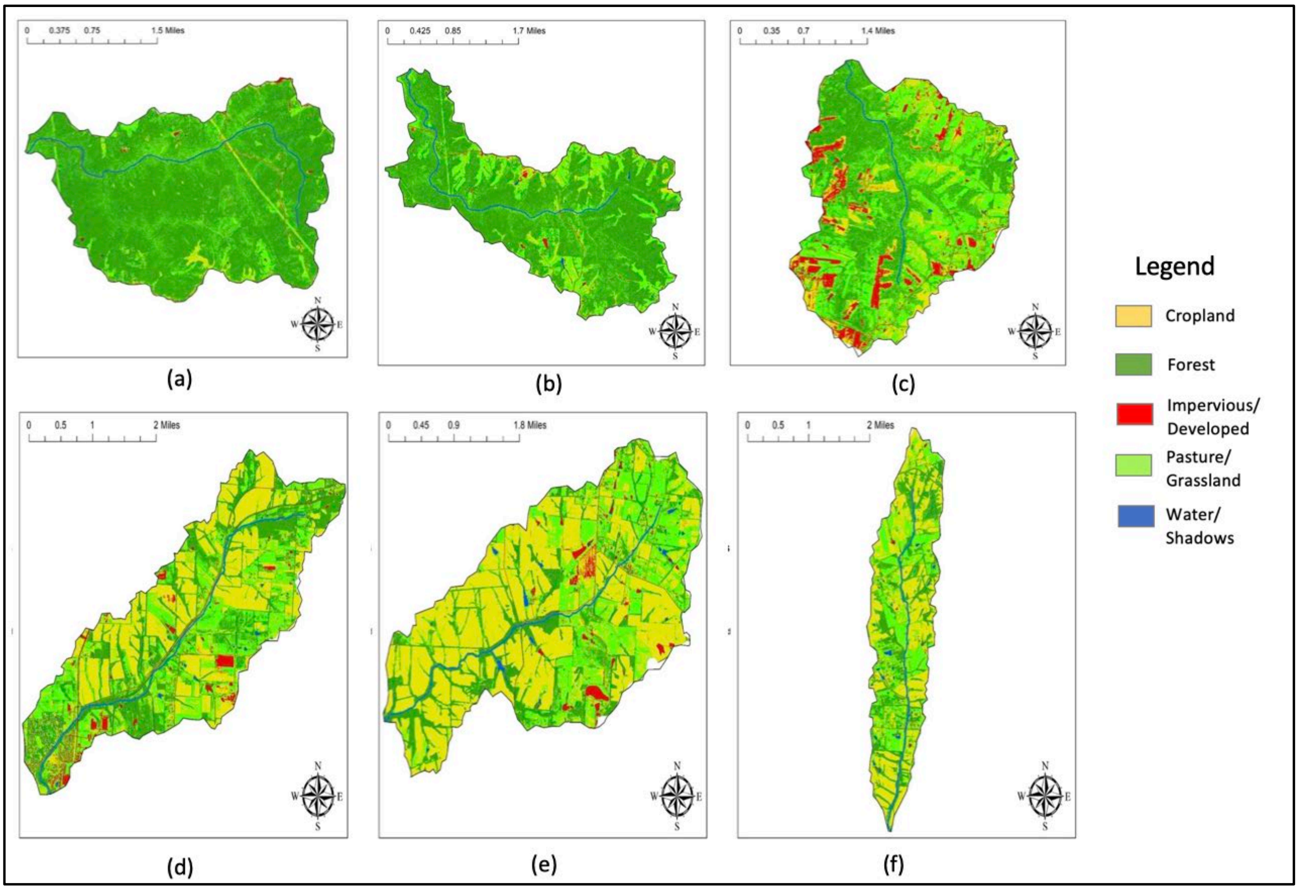


Figure 4. (**a**) Site 2—Woodcocks branch classified raster; (**b**) Site 3—Little Sixmile Creek classified raster; (**c**) Site 4—Indian Fork Creek classified raster; (**d**) Site 6—Mulberry Creek classified raster; (**e**) Site 7—East Clear Creek classified raster; (**f**) Site 8—Lutz Run Creek classified raster.

Sites 2 and 3 exhibited significantly higher land cover percentages for each stream drainage area (68.12% and 60.0%, respectively) of the forested land class (Table 1). Site 4 also resulted in a dominant forested area of 32.8%, which was primarily a riparian zone. Forested watershed stream sites showed minimal cropland, developed/impervious, and water/shadows classes. In the agriculture watershed, cropland dominated, with Site 7 having the highest percentage (54.2%), followed by Site 8 (43.27%) and Site 6 (39.2%). Sites 6 and 8 showed higher forested and pasture/grassland percentages than Site 7. Water/shadows and developed/impervious classes are minimal in all agriculture watershed stream sites. Forested land near streams was limited, occurring mainly in isolated pockets within each stream drainage area away from the actual stream.

Table 1. Land cover percentages of sampled stream sites.

Land Cover Class	Site 2 (%)	Site 3 (%)	Site 4 (%)	Site 6 (%)	Site 7 (%)	Site 8 (%)
Water/shadows	4.15	3.21	1.13	2.81	2.45	3.99
Impervious/developed	0.97	1.21	7.89	4.29	2.77	1.22
Forest	68.12	59.99	32.8	25.32	16.73	20.91
Cropland	4.08	6.06	17.35	39.20	54.20	43.27
Pasture/grassland	22.68	29.33	40.83	28.38	23.85	30.60

Water quality parameters were compared between forested and agricultural streams to determine if any significant differences occurred between the cover types (Table 2). Dissolved oxygen (DO) was found to be significantly lower ($p < 0.0001$) for the agricultural streams (8.15 mg/L) compared to forested streams (8.98 mg/L). There was no significant difference found in regard to stream temperature (p = 0.1409). The stream pH was significantly lower (p = 0.0480) for agricultural streams (7.67) than forested streams (7.72). Total suspended solids (TSS) were significantly greater (p = 0.0083) for agricultural streams (45.76 mg/L) compared to forested streams (38.06 mg/L). The TSS discharge was also found to be significantly higher for agricultural streams (8000.58 mg/s) than forested streams (2847.66 mg/s). Lastly, the stream flow was significantly greater for the agricultural streams (4.73 m^3/s) than the forested streams (1.63 m^3/s). Letters 'A' and 'B' represents groupings that are not significantly different from each other according to Fisher's LSD test.

Table 2. The difference of mean water quality parameters depending on land cover (agriculture and forested).

Parameter	Land Cover	Mean		***p*-Value**
DO (mg/L)	Ag	8.15	A	<0.0001
	Forested	8.98	B	
Temperature (°C)	Ag	20.35		0.1409
	Forested	19.80		
pH	Ag	7.67	A	0.0480
	Forested	7.72	B	
TSS (mg/L)	Ag	45.76	A	0.0083
	Forested	38.06	B	
Flow (m^3/s)	Ag	4.73	A	<0.0001
	Forested	1.63	B	
TSS discharge (mg/s)	Ag	8000.58	A	0.0002
	Forested	2847.66	B	

Water quality parameters were also evaluated by season (spring, summer, and fall) and land cover to determine if any differences occurred by season in the agricultural and forested streams (Table 3). The same water quality parameters were assessed with the addition of season to the model. All two-way ANOVA models were significant ($p < 0.05$); however, there were no significant interactions between land cover (ag/forested) and season. Significant seasonal differences occurred for the pH. Significant seasonal differences for both the agricultural and forested streams included DO, temperature, pH, and TSS. DO was significantly low in the summer for both the agricultural (7.38 mg/L) and forested streams (8.5 mg/L). TSS levels for the agricultural streams were significantly greater ($p < 0.0011$) in the spring (53.66 mg/L) and summer (49.04 mg/L) than in the fall (33.28 mg/L), while TSS levels in the forested streams were significantly greater only in the spring (49.54 mg/L) than the summer (35.62 mg/L) and fall (29.30 mg/L). Letters 'A', 'B' and 'C' represent groupings that are not significantly different from each other according to Fisher's LSD test.

Several water quality parameters were significantly ($p < 0.05$) correlated within the agricultural and forested streams (Table 4). However, only a few water quality parameters were moderately to strongly correlated. In the agricultural streams, those parameters consisted of stream flow and TSS discharge (r = 0.85), temperature and DO (r = 0.70), TSS and TSS discharge (r = 0.62), and pH and DO (r = 0.58). Forested streams' moderately to strongly correlated parameters were stream flow and TSS discharge (r = 0.93), TSS and TSS discharge (r = 0.62), TSS and stream flow (r = 0.56), and pH and DO (r = 0.56).

Table 3. Effect of season and land cover on mean water quality parameters.

Land Cover	Parameter	Season	Mean		*p*-Value
Ag	DO (mg/L)	Spring	8.34	B	<0.0001
		Summer	7.38	C	
		Fall	8.82	A	
	Temperature (°C)	Spring	20.75	B	<0.0001
		Summer	22.41	A	
		Fall	17.61	C	
	pH	Spring	7.84	A	<0.0001
		Summer	7.62	C	
		Fall	7.72	B	
	TSS (mg/L)	Spring	53.66	A	0.0011
		Summer	49.04	A	
		Fall	33.28	B	
	Flow (m^3/s)	Spring	4.71		0.7427
		Summer	4.29		
		Fall	5.24		
	TSS discharge (mg/s)	Spring	9804.75		0.5934
		Summer	7248.73		
		Fall	6980.17		
Forested	DO (mg/L)	Spring	9.08	A	0.0003
		Summer	8.50	B	
		Fall	9.441	A	
	Temperature (°C)	Spring	20.05	B	<0.0001
		Summer	21.50	A	
		Fall	17.66	C	
	pH	Spring	7.84	A	<0.0001
		Summer	7.59	B	
		Fall	7.84	B	
	TSS (mg/L)	Spring	49.54	A	<0.0001
		Summer	35.62	B	
		Fall	29.30	B	
	Flow (m^3/s)	Spring	2.26		0.1013
		Summer	1.21		
		Fall	1.37		
	TSS discharge (mg/s)	Spring	4619.67		0.0930
		Summer	2431.56		
		Fall	1561.12		

Table 4. Pearson correlation comparing water quality parameters for both agricultural and forested streams.

Land Cover	Parameter 1	Parameter 2	r	*p*-Value
Ag	Flow	TSS discharge	0.85	<0.0001
	Temp.	DO	0.70	<0.0001
	TSS	TSS discharge	0.62	<0.0001
	pH	DO	0.58	<0.0001
	TSS	Flow	0.27	<0.0001
	DO	Flow	0.23	0.0007
	Temp.	pH	0.22	0.0009
	pH	TSS	0.17	0.0110
	Temp.	Flow	0.16	0.0200
	DO	TSS	0.15	0.0269

Table 4. *Cont.*

Land Cover	Parameter 1	Parameter 2	r	*p*-Value
Forested	Flow	TSS discharge	0.93	<0.0001
	TSS	TSS discharge	0.62	<0.0001
	TSS	Flow	0.56	<0.0001
	pH	DO	0.56	<0.0001
	DO	TSS	0.25	0.0002
	Temp.	pH	0.22	0.0011
	Temp.	DO	0.18	0.0081
	pH	Flow	0.18	0.0105

4. Discussion

Water quality impacts were assessed according to compliance with the Kentucky Water Quality Standards [15]. These standards serve as minimum requirements for all surface waters in Kentucky, as well as for maintaining and protecting them for designated uses. This study found that both forested and agricultural streams maintained pH values within acceptable limits for aquatic life (6.0 to 9.0 pH units) [15]. Notably, forested streams had a significantly higher mean pH than agricultural streams; however, pH values did not fall outside the limits for aquatic life. The water temperature was not different between the agricultural and forested streams and remained within the acceptable range for aquatic life [32].

DO levels in the forested streams were greater than in the agricultural streams, and TSS and TSS discharge levels were greater in the agricultural streams than in the forested streams. This indicates that streams in forested areas have better water quality and a greater potential to support diverse aquatic life compared to agricultural streams. TSS levels were also greater for agricultural streams during the spring, indicating that the tilling and planting seasons likely result in greater erosion. A potential necessity for expanded (wider) riparian zones beyond what is currently implemented to safeguard stream water chemistry and support greater aquatic diversity. Similar trends have been reported in various studies, emphasizing the superior water quality in forested watersheds compared to agricultural ones [33–36]. For instance, a study in the Lower Grand River Watershed in Missouri demonstrated significant correlations between geologic and land use characteristics and water quality parameters in 35 independent sub-watersheds [14]. The most forested watershed exhibited the best water quality, while the predominantly agricultural watershed displayed the poorest quality and greatest temporal variation [31]. The results from other studies also highlight the positive influence of forest cover on water quality indicators over specific periods [37,38].

Higher forest cover has been associated with increased dissolved oxygen (DO) concentrations [39], a pattern observed in our study where DO levels remained above the threshold and were significantly greater than the levels in the agricultural streams. In our study, forested sites consistently exhibited lower TSS concentrations compared to agricultural sites, with instances of TSS levels nearing 80 mg/L. Elevated TSS levels have been associated with adverse effects on aquatic life, including mortality in eggs and larvae, gill damage in certain fish species, and increased mortality among juvenile salmonids; effects observed from levels as low as 25 mg/L up to increased mortality at 500 mg/L [40,41]. Studies have indicated that changes in land cover, particularly increased cropland, can lead to elevated TSS concentrations, suggesting agriculture is a potential contributor to increased sediment levels [42]. Research has shown a correlation between a decrease in forest cover and increased turbidity, TSS, and total dissolved solids (TDS) by 8.41% and 4.17%, respectively [43]. The Pearson correlation analysis results for this study indicate a correlation between pH and DO. Similar results were found in other studies [44,45]. Zhang (2009) reported a correlation of 0.51 between pH and DO [46], while our study reported a correlation of 0.58 for agricultural streams and 0.56 for forested streams.

There are significant differences in water quality parameters between agricultural and forested streams despite the presence of riparian zones along the agricultural stream's banks. This suggests the potential benefits of expanding riparian zones beyond what farmers currently have along their streams. The Kentucky Agriculture Water Quality Act mandates water quality plans for landowners with 10 or more acres. There are suggested practices for controlling/limiting erosion in agriculture, but they are only regulated if there is a traceable infraction. Forestry BMPs are regulated under the Kentucky Forest Conservation Act, and timber harvest sites are evaluated for BMP implementation and potential erosion/sedimentation infractions [29,47]. BMPs include guidelines for reducing nonpoint source pollutants and protecting water quality, emphasizing streamside management zone width and erosion control practices [29]. Expanding riparian forests could help mitigate nonpoint source pollution in Kentucky's waterways, highlighting the importance of forests for local biological systems and the need for further evaluation of BMP implementation on agricultural lands.

However, the study has some limitations related to the challenges in land cover classification stemming from class overlapping, which could be improved with more bands than the current four. Technical constraints, including a large mosaic size and limited ground-truthing, make precise land cover quantification challenging. Despite these limitations, aerial imagery and computer-based classification offer valuable generalized views for land management. The lack of long-term data collection and historical data hampers our understanding of temporal changes. Future research is needed in additional watersheds, and there is a need to be able to collect long-term data. Additionally, the assessment of water quality may be influenced by numerous additional variables not accounted for in this study, such as precipitation and weather events, which should be considered in future studies.

5. Conclusions

The research utilized a data-intensive approach and a comprehensive GIS sampling framework to investigate agriculturally related nonpoint source water pollution in Central Kentucky's outer Bluegrass region. Significant differences in water quality parameter values between agricultural and forested streams were found. Forested streams' water quality suggested a potentially more suitable aquatic environment compared to agricultural streams. The disparities in water quality parameters in agricultural streams raise concerns about the potential negative impacts on local biota by altering water chemistry beyond known biological limits for supporting aquatic life. Additionally, an association was observed between the percentage of agricultural land in stream drainage areas and the extent of variation in water chemistry parameters from the overall mean. This finding suggests a possible threshold in land cover percentages that can influence water chemistry, which could inform watershed management plans for mitigating nonpoint source water pollution.

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