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Impact of hydraulic fracturing induced landscaping change on regional surface water quality in eastern Ohio

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Abstract

The impacts of unconventional exploration of oil and gas in eastern Ohio on local landscape and regional surface water quality were studied. The landscaping alteration associated with unconventional exploration resulted in deforestation and increased the impervious and developed land areas on regional scale. It accelerated the movement of water and sediment across the landscape causing a deterioration in surface water quality. A total of ten surface water sampling sites were selected along surface streams in two Ohio counties where hydraulic fracking oil and gas exploration boom was observed in the past decade. Drainage areas were delineated around each sampling site using USGS StreamStats online tool. Land use and land cover were investigated for each delineated drainage area for 2013 and 2019 to study the changes in landscaping patterns. Forest land areas have maintained their steady percentage (with less than ±1% changes) in the majority of the investigated drainage basins since 2013; during the same period, developed land areas have increased by a range of 1.5% to 4.7%. Additionally, landscaping fragmentation was studied using FRAGSTATS to assess the class-level fragmentation of the forested land. Forest patch number within the drainage areas were not observed with significant variations since 2013, which suggest a minor or neglectable deforestation within the region. Surface water sampling were carried out in 2018 and 2019 by collecting surface water samples from two streams and one reservoir. Eleven water quality parameters, including pH, dissolved oxygen, total suspended solids, conductivity, nitrate, Ba, Sr, Ca, and etc., were analyzed onsite and in the lab. Principal Component Analysis showed elevated impacts on water quality in the upstream sampling sites near the unconventional oil and gas well drilling fields. Strong positive correlations (coefficient values close to +0.9) were reported between developed land percentage and metal element concentrations, as well as forestry patch number and turbidity.

Key Words: Undergraduate Research, Hydraulic Fracturing, Landscaping Change, Surface Water Quality, Land Fragmentation

1. Introduction

Unconventional horizontal hydraulic fracturing (fracking) of shale deposits for oil and natural gas exploration has dramatically increased in the last decade, particularly in the eastern United States along Marcellus and Utica formations underlying the Appalachian basin. Several environmental concerns such as depletion of water resources, contamination of water bodies by fracking wastewater, and increase in impervious surfaces due to rapid landscaping have not been well studied. These changes may compromise natural ecosystem and regional surface water quality if proper sustainable measures are not introduced to the operation.

The state of Ohio has a total land area of 26.4 million acres. According to a USDA report (Oswalt et. al., 2019), approximately 8 million acres of Ohio land are classified as forest land and located in eastern Ohio within the Allegheny Plateau region. Between 2011 and 2016, there was a total of 91 thousand acres net loss in forest land reported (Albright, 2017). Starting from 2012, more than 2,800 unconventional hydraulic fracturing wells were permitted by Ohio Department of Natural Resources (ODNR) to drill into the shale formations and produce oil and gas. Up to 2019, approximately 1900 active wells in Ohio are undergoing oil and natural gas productions; 303 wells have completed well drilling; 156 wells are conducting well drilling and prior production preparation; and over 400 wells are granted for permits and will start hydraulic fracturing drilling and production soon. Majority of these wells are in eastern Ohio forests. Compared with conventional shallow well drilling, a larger land area (known as well pad) needs to be converted to impervious land for a single unconventional deep well to accommodate all the drilling and fracturing infrastructure (Drohan et al., 2012). Each well pad can expand from 3 – 7 acres depending on the number of drilling wells installed. Other than these primary infrastructures, several auxiliary infrastructures need to be constructed for transportation, onsite flowback fluids storage, compressor stations, and gathering pipelines. Overall, about 30 acres of land will be converted from original land cover to impervious land for a single well pad. Figure 1 shows the satellite image for an example of a hydraulic fracturing well pad and its auxiliary infrastructures developed in a forestry area. Currently, state of Ohio has established regulations directing safe operations in hydraulic fracking waste disposal, deep well injection, spill prevention during storage and transportation, but has not yet developed any sustainable management strategies of issuing well pad permits and selecting well pad locations in order to protect and conserve local ecosystem, natural resources and wildlife species.

Figure 1. Satellite image for a converted well pad with its auxiliary infrastructures.

Meanwhile, forest fragmentation has been observed in the early stage of the development due to a large number of well pads constructed in the region (Drohan et al., 2012). A further increase in exploration without proper restoration measures may increase forest fragmentation. It can transfer the original large, contiguous forest area into several small, distinct forest patches, which can further reduce the size of core ecosystem habitat, increase the edge length of the forest, and eventually contribute to the reduction in wildlife species population and diversity. Additionally, the temporarily or permanently cleared forest areas increase the surface runoff and contribute to soil erosion. These negative consequences can release pollutants and sediments into regional surface water. The long-term accumulation of these contaminants can cause deterioration of regional surface water quality and loss of aquatic habitats due to the increase of bottom sediments.

This study assessed the impacts of unconventional well drilling and production in eastern Ohio on the local surface water quality. Tuscarawas subbasin was selected based on the unconventional oil and gas production survey to carry out both investigations on landscaping alteration and water quality variations. The landscaping alteration were monitored by studying the changes to three major land use classes (i.e., forestry land, agricultural land and developed land) between 2013 and 2019. Ten stream sites within the upstream area of the Tuscarawas subbasin were identified for surface water sampling and drainage areas delineation. Moreover, forest fragmentation was assessed for the delineated drainage areas. Overall, the focus on a subwatershed allowed us to solely understand the impacts of -production-induced landscaping alteration, and associated changes to water quality. Statistical analysis was used to determine the temporal and spatial variations in local surface water quality within the sub-basin and aided to correlate the changes in water quality with landscaping alteration and energy production activities. The project results are also expected to assist the establishment of state guidelines and policies to introduce sustainable management strategy into the unconventional energy production. Additionally, this project aims to engage undergraduate students on research and provide them with experiential learning opportunities to expand the curriculum contents to scientific and industrial application.

2. Institutional Background and Student Engagement

The project was carried out at Central State University lead by a group of five faculty members. Central State University (CSU) is a public owned undergraduate Historical Black University (HBCU). With its 1890 Land grant designation, CSU is committed to provide experiential education and training to underrepresented communities. In recent years, CSU has experienced decline in student retention and enrollment, especially in the STEM programs. Retention of students is found to be difficult due to the lack of preparation in math and English. Summer engagement on research activities has been proven to be effective in retaining students and better preparing them for upcoming academic studies. Therefore, this five-year research project also carries out the mission to support and retain students majored in Environmental Engineering (ENE) program.   It has been found that research based learning strategy can outreach students in STEM programs during the summer break and better prepare them for incoming academic studies. Throughout the implementation of the project, undergraduate students at Central State University were offered with opportunities to participate in research projects, training of lab skills, and practice using software to perform data analysis and modeling.

Over the past five years, undergraduate students at CSU were involved in the research activities sponsored by this project in both lab and field. Students were trained to perform three primary tasks: 1) surface sample collection and in situ field measurement; 2) lab analysis of water quality parameters via advanced instrument; 3) data analysis using statistical software. Other than these primary tasks, students also learned to download data from national wide database, use multiple online tools to obtain map and other auxiliary information (e.g., well pad survey, hydrography data), and delineate drainage areas to assist the completion of research objectives. Student participants were engaged in the project work for one to two summer or academic semesters, and they were rotated among different research tasks to receive comprehensive preparations for both future academia and industrial employment. Tasks were carefully designed to build connections to the environmental engineering curriculum. Particularly, demonstration of design and engineering concepts were particularly given to social, economic, and sustainable considerations.

3. Study Area

The Muskingum basin located in the eastern Ohio was selected for oil and gas activity inventory study as most of the unconventional drilling was observed to take place in the east central Ohio. The Muskingum basin is the largest watershed that completely located within Ohio. It has a total drainage area over 8,000 square miles. The predominant land uses in the Muskingum basin include urban, agriculture and forest, with the forest area mostly found in the southeast of the basin. The mainstream, Muskingum River, starts at the central east Ohio from the confluence of two major regional streams, Tuscarawas River and Walhonding River. It flows towards south and discharges into the Ohio River. Tuscarawas subbasin locates in the upper east of the Muskingum basin with a total drainage area of 2,600 sq miles (U.S. Army Corps of Engineers, 2018). Starting from 2008, the sub-basin has been observed with the boom of unconventional oil and gas drilling activities in recent decade. The Tuscarawas sub-basin is traditionally dominated by a mixture of forest land (40% in 2001) and agricultural crop fields (39% in 2001) with pasture areas for livestock farming nearby (Haefner and Simonson, 2010). As the unconventional oil and gas exploration started, the landscape on the eastern Tuscarawas subbasin was rapidly altered that has raised the concerns on long term regional water quality as the consequences of increased surface runoff and transportation of ground level contaminants, such as fertilizer and agricultural wastes, into the nearby surface water (Austin, et al., 2018). However, the watershed with large size generally is found not sensitive to the landscaping change on patch scale. Therefore, the main study area for water quality variation investigation is further zoomed in to the headwater area of the subbasin to further focus on subwatersheds (12 HUC digits drainage basins).

Well pad locations and well summary reports in Tuscarawas sub-basin were acquired from Ohio Department of Natural Resources website (ODNR). Well pad numbers were counted for each delineated drainage basin and their densities calculated by dividing the pad numbers by the drainage area. Harrison, Guernsey, and Carroll are the three major counties in the Tuscarawas watershed experiencing intense fracking. Carroll County was reported with the highest well pad density among these three.

Surface water in subwatersheds typically is found more sensitive and tend to respond relatively faster to anthropogenic development impacts than that in large drainage basins. The ten selected sampling sites (IR1-5 along Irish Creek; CO1-2 along Conotton Creek; and LE1-3 in Leesville Lake) are located in the headwater areas of the Tuscarawas subbasin with all their drainage areas less than 130 km^2 except site CO2 (Table 1). Specifically, Irish Creek located on the boundary of Carroll and Harrison County flows from the east towards southwest, eventually confluence into the Conotton creek and drain together into Tuscarawas River (Figure 2). The Leesville Lake is a regional artificial reservoir primarily used for flood control and recreation activities by the local community. Site ID number increases as the sampling site moves from up to down stream. Table 1 shows the drainage area along with the oil and gas activities in it for ten sampling sites.

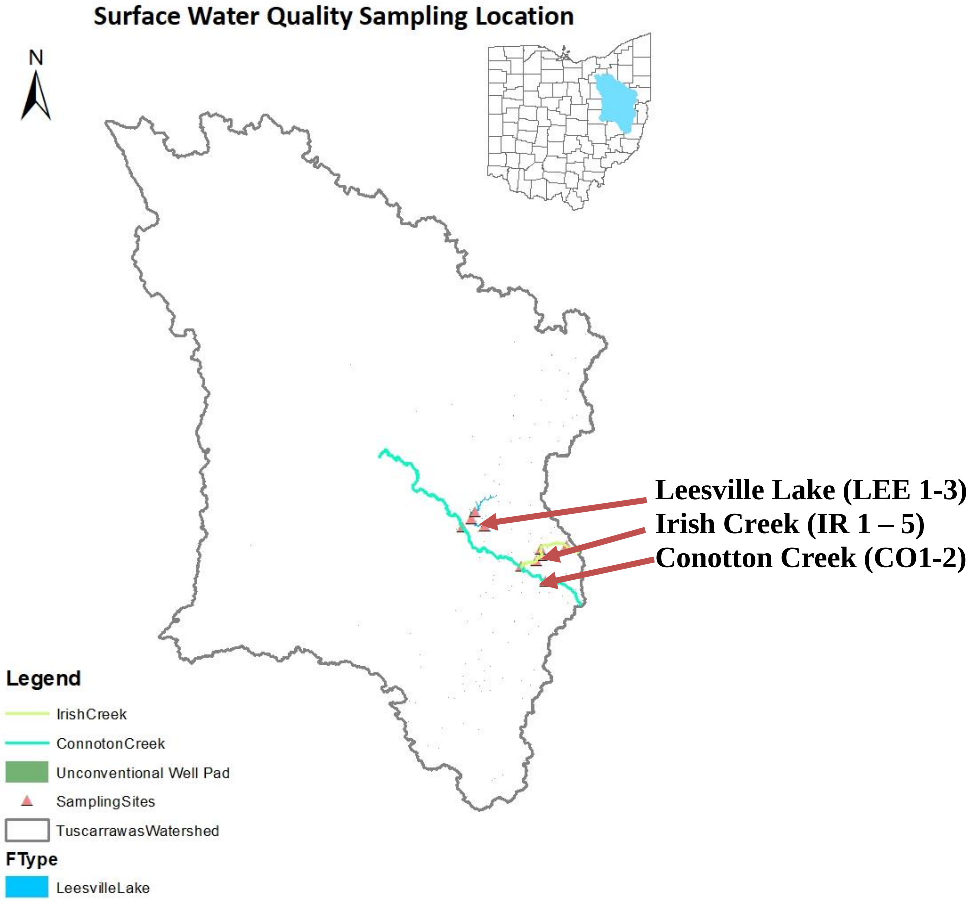

Figure 2. Study area and sampling sites in Tuscarawas subbasin.

4. Methods

4.1 Landscaping alteration

USGS StreamStats online tool was used to delineate the drainage areas around each sampling site (U.S. Geological Survey, 2016). Land Use data was downloaded from Multi-Resolution Land Characteristics (MRLC) Consortium for 2013 and 2019. The land use types for the delineated drainage areas were classified based on MRLC raster files with a 30-m resolution. Land cover was studied in each delineated drainage areas for both 2013 prior to the boom and 2019 after the boom to investigate the landscaping alteration during the study period. The area percentage changes of each land cover class were calculated by comparing the 2013 areas to the 2019 areas for each delineated drainage area. Additionally, hydrography data were downloaded from the USGS National Map (TNM) Viewer database and the forest fragmentation was studied using FRAGSTATS to count forestry patch number for the delineated drainage areas for 2013 and 2019 (McGarigal, Cushman, & Ene, 2012).

Table 1. The drainage areas for sampling sites along with well pad numbers and densities.

Site ID	Streams / Reservoir	Drainage Area (Sq km)	No. of Well Pads within Drainage Area	Well Pad Density (no/sq. mi)
IR1	Irish Creek	3.29	0	0
IR2	Irish Creek	22.90	7	0.79
IR3	Irish Creek	24.84	7	0.73
IR4	Irish Creek	41.70	11	0.68
IR5	Irish Creek	48.69	12	0.64
CO2	Conotton Creek	232.58	43	0.48
CO1	Conotton Creek	44.29	4	0.23
LEE1	Leesville Lake	49.47	10	0.52
LEE2	Leesville Lake	68.89	10	0.37
LEE3	Leesville Lake	65.00	10	0.40

4.2 Water quality data collection

Grab water samples were collected from each sampling site on the surface of the stream for two seasons (i.e., fall and spring) in 2018 and 2019. One sample was collected for fall, and three samples were collected in the following spring for comparison except CO1 and CO2. Both CO1 and CO2 were only sampled for once in 2019. Collected water samples were preserved with ice during transportation and stored in refrigerator at 4 °C before analysis. Sampling procedure follows the Surface Water Field Sampling Manual (Ohio EPA, 2018).

Physical water quality parameters (Dissolved Oxygen, Temperature, pH, conductivity, and turbidity) were measured onsite with YSI ProDSS multiparameter water quality meter. Chemical constitutes (metal elements and nitrate and total reactive phosphate) of the water samples were tested in lab using Agilent 7900 MS-ICP and Hach TNTplus nutrient analysis kits. Total suspended solids (TSS) were measured using gravimetric method according to EPA methods 160.2. Then, mean values were taken to parameters obtained at different time for the same sampling site. The single values were used for those sites with only one sampling activity performed.

4.3 Statistics Analysis of Water Quality Data

The variation in water quality at different sampling sites across the seasons in 2018 and 2019 were determined by statistical analysis using RStudio (version 1.4.1). PCA was conducted using RStudio to condense the dataset comprising of eleven water quality parameters into principal components that correlate well with the locations in the vicinity of collection sites experiencing landscape pattern change from an increased oil and gas activity. Water quality data used in the PCA were collected between September 2018 and July 2019, including pH, Dissolved Oxygen, turbidity, conductivity, TSS, nitrate (NO_3), potassium (K), magnesium (Mg), calcium (Ca), strontium (Sr), and barium (Ba). A total of 20 water samples were analyzed, and their values log-transformed for use in the PCA analysis. Mean values of major water quality variance were used to exam their correlations with landscaping and forestry fragmentation parameters based on Pearson Correlation test.

5. Results and Discussion

5.1 Retention and Graduation of Student Participants

A total of 8 undergraduate students and one graduate student (not included in the student graduation survey) were engaged in the project over the five-year period. All undergraduate students have been retained in ENE program and work successfully towards graduation. One of the engaged students is part time enrolled (PTE) in the program, so the data on that participant is not included in the survey results, and all others are full time (FTE) students. Five of the student participants were first time enrolled with weak preparation in math (i.e., not ready for Calculus I in their first year), which put them on the five year graduation roadmap. By the end of 2021 – 2022 academic year, five of them have graduated; the other three are on track to graduation in 2022 – 2023 academic year. Table below summarize the undergraduate student participant graduation schedule and post career employment.

Table 2. Undergraduate participant retention and graduation summary.

Student ID	Classification	Participation level	Status	Postgraduation Career	External Internship	GPA	No. of years enrolled (enter year - graduate year)
S1	FTE Undergraduate	Research assistant	Graduated	Engineer	Yes	3.70	4 (2016 – 2020)
S2	FTE Undergraduate	Field work and lab analysis	Graduated	Entrepreneur	Yes	2.32	10 (2010 – 2020)
S3	FTE Undergraduate	Field work and software modeling	Graduated	Design Engineer	No	3.08	5 (2016 – 2021)
S4	FTE Undergraduate	Field work	Graduating Senior	Process Engineer	Yes	3.26	5 (2017 – 2022)
S5	FTE Undergraduate	Field work	Graduating senior	Masters with scholarship	Yes	4.00	5 (2017 -2022)
S6	FTE Undergraduate	Field work; Software modeling	Junior	NA	No	3.55	5 (2018 – expected 2023)
S7	FTE Undergraduate	Field work; Software modeling	Junior	NA	No	3.40	4 (2019 – expected 2023)
S8	PTE Undergraduate	Lab analysis	Junior	NA	Yes	4.00	NA

Overall, the retention rate for student participants involved in this project is 100%; and five-year graduation rate is 85.7% (6 out of 7 graduate in five years). According to the data published by Central State University 2021 Factbook, the most recent five-year graduation rate across CSU campus is 25%, and total graduation rate for 2014 cohort is 28%. Retention rate reported for CSU First Time Enrolled student was 40%, 47%, 54%, 46% and 56% for cohorts enrolled between 2015 and 2019. In addition, all students engaged in this project have achieved cumulative GPAs greater than 3.0 except one participant, which indicates successful progress in their academic learning compared with the average high school GPA reported for the First Time Enrolled freshmen at CSU of 2.80. This suggests that undergraduate research experience can provide extra trainings and practice opportunities to students outside their traditional classrooms. The combination of lecture based teaching and project based application can substantially improve the teaching effectiveness and foster better understanding of concepts and skills.

5.2 Unconventional Oil and Gas Exploration in Ohio

The oil and natural gas production from several wells tapping into Utica shale in the study region were aggregated between 2012 and 2018. Well permits were increased to 200 per year between 2010 and 2013 and dropped to 50 per year in 2015. As oil and gas production peaked from 2012, a change in land use was observed mostly from hay/crops to pad areas and pipeline ROWs. Peak production as shown in Figure 3 occurred between 2012 and 2015 over 1 km^2 of pad area within HUC 12 drainage basin.

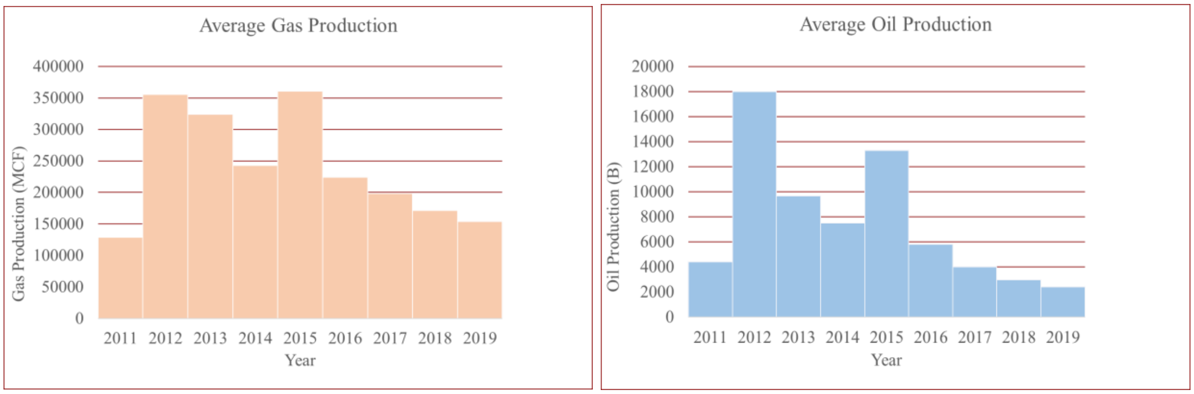

Figure 3. Oil and gas production between 2011 and 2019.

5.3 Landscaping alteration

The study area in this research was traditionally dominated by two major land use classes (forest and agricultural land) that are intertwined with each other. This unique setting along with rapid land transformation from covered to developed land is suspected to introduce multiple agribusiness products into nearby streams. Hence, three major land use classes were selected to study their changes in 2013 and 2019. More than 80% of the well pads construction within the study area were started in 2014 and the land transformation has slowed down or completely paused approximately in 2018. Therefore, 2013 was selected to investigate the prior boom landscaping pattern; 2019 was selected for the post boom landscaping investigation. This study period also correlates well with oil and gas production boom as shown in Fig. 1. Overall, land use pattern is not observed with changes greater than ±5% within the study period in all delineated drainage areas. Among the three studied classes, developed land percentage is observed with greatest increases by a range of 1.5 – 4.7% except in IR1 drainage area. The highest increase in development land occurred in the drainage areas associated with Leesville sites (3.0 – 4.7%), followed by the drainage areas for sites along Conotton Creek and Irish Creek (1.5 – 2.6%). However, with the low percentage of developed land (only 1%) in the drainage area, similar changes in the forested and agricultural lands are not observed. Forestry land in the ten delineated areas experienced changes by a range of +0.26 to -1.47%. Agricultural land changes to the smallest degree by a range of +0.17% to -1.06%.

The forest patch number have slightly decreased or remained the same from 2013 to 2019 in most of the delineated drainage areas. This positive change indicates the mitigation of forestry fragmentation and may be attributed to the restoration of the land cover around completed well pads through the planting of grass and other vegetation (Donnelly et al., 2017).

Table 3. Landscaping configuration and number of forest patch for each sampling site drainage area and percentage change for major land use classes (Forest Land, Agricultural Land, Developed Land) in 2013 and 2019.

	2013				**2019**				**% Change**		
Site ID	**For Land%**	**Ag Land %**	**Dev Land%**	**Forest NP**	**For Land%**	**Ag Land %**	**Dev Land%**	**Forest NP**	**For Land**	**Ag Land**	**Dev Land**
IR1	58.28	33.35	7.57	47	57.79	33.35	7.57	47	-0.841	0.000	-0.032
IR2	56.54	34.8	6.7	221	56.69	34.86	6.86	213	0.265	0.172	2.388
IR3	57.18	34.22	6.51	242	57.31	34.27	6.67	234	0.227	0.146	2.458
IR4	55.7	36.31	6.61	457	55.77	36.33	6.71	449	0.126	0.055	1.517
IR5	57.3	34.58	6.73	542	57.39	34.57	6.85	529	0.157	-0.016	1.783
CO1	53.9	34.5	8.95	513	53.7	34.5	9.1	520	-0.371	0.000	1.676
CO2	54.4	28.4	7.6	2759	53.6	28.1	7.8	2789	-1.471	-1.056	2.632
LE1	55.7	33.7	6.99	645	55.4	33.5	7.2	646	-0.539	-0.593	3.004
LE2	63.83	25	6.35	820	63.74	24.8	6.63	804	-0.141	-0.800	4.409
LE3	63.41	26.05	6.32	757	63.35	25.86	6.62	743	-0.095	-0.729	4.747

5.4 Surface water quality variations

The data collected in the past by the Ohio Department of Health and the Ohio Department of Natural Resources showed a continuous decline of surface water quality in Tuscarawas subbasin over a long period (Haefner and Simonson, 2010). The decline was primarily attributed to agricultural and historical mining, oil, and gas drilling activities within the basin. The spatial changes in mean water quality parameters across the sampling period were shown in Table 4. The mean nitrate levels increase from the upstream to downstream in both Irish and Conotton creeks. The key elemental levels, such as Ca, Ba, and Sr decreased from upstream to downstream. These elements were reported to associate with unconventional oil and gas production.

Table 4. Mean values of water quality at sampling sites along Irish Creek, Connotton Creek and Leesville Lake in 2018 and 2019.

Site ID	pH	Temp (°C)	DO (%)	Turbidity	Cond. (µs/cm)	N-NO$_3$ (mg/L)	TSS (mg/L)	Mg (ppm)	K (ppm)	Ca (ppm)	Sr (ppm)	Ba (ppm)
IR1	7.83	14.78	106.93	13.75	599.67	0.60	4.00	27.62	3.79	28.19	0.34	0.06
IR2	7.43	15.10	98.05	13.75	221.00	0.66	8.00	5.02	1.57	7.27	0.22	0.08
IR3	8.3	15.1	98.05	13.75	221	0.66	8.00	5.020	1.574	7.270	0.224	0.081
IR4	7.7	17.2	101.3	27.875	246	1.00	21.33	9.247	3.027	9.729	0.141	0.0375
IR5	NA	20.7	93.2	20	206.4	1.39	34	11.272	3.962	11.283	0.161	0.055
CO1	NA	20.6	104.6	6.5	571	1.71	6	45.497	4.229	33.155	0.507	0.065
CO2	7.83	17.6	96.5	133	401.8	2.15	22	23.193	3.666	18.088	0.323	0.071
LE1	8.515	15.75	114.5	3.6	190.25	0.52	268	6.4285	2.073	7.240	0.103	0.036
LE2	8.335	15.6	111	2.2	175.75	0.58	7	6.611	2.3305	7.500	0.105	0.0655
LE3	8.335	15.95	112.8	2.45	173.95	1.34	27	7.117	2.4545	8.203	0.117	0.064

PCA was conducted to identify the primary water quality variances and locations undergoing significant water quality changes. The principal components (PCs) with eigenvalues greater than one were suggested to be employed for further analysis (Olsen et al., 2012). Principal component scores were calculated for all quality observations. Figure 3 shows eigenvalues (variances) for 9 components. The first four PCs (i.e., PC1, PC2, PC3, and PC4) describes a total of 91.2% of the original data variance, which also indicates that the selected PCs (PC1-4) contain the majority of the information in the original dataset.

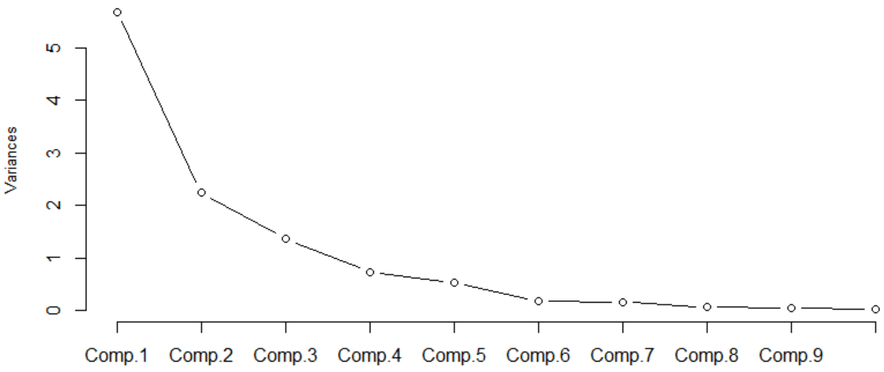

Figure 3. Eigen values for 9 Principal Components.

Table 5 shows the individual contribution of each water quality parameter to the first four principal components. These contributions are commonly referred scores. PC scores of original parameters greater than 0.3 or smaller than -0.3 were considered significant (McGarigal et al., 2000). Specifically, high positive PC1 values was characterized by the elevated conductivity, Mg, K, Ca, Sr, and Ba; high positive PC2 values indicated the increase in pH, DO and decrease in turbidity. The missing PC scores for some water quality variances were due to the missing of original data. The corresponding parameters within those components were suggested as major contributors to the data variance.

In addition, Figure 4, with PC1 coordinates plotted over PC2, provides a general view of the spatial variations of the water quality data. High positive PC1 scores were reported on conductivity and metals associated with observation 10 and 17 which were both collected from IR1. High positive PC2 scores on pH and DO were found associated with observation 16 and 15 collected from Leesville Lake sites (LE3 and LE2). These results indicate that the elevated conductivity and metals are primarily found at the upstream site with short distance to the well pads.

Table 5. PC scores for all water quality variables for selected PCs.

Principal Components (PCs)	**PC1**	**PC2**	**PC3**	**PC4**
Proportion of Var (%)	51.8	20.4	12.4	0.066
Cumulative Var (%)	51.8	72.2	84.6	91.2
pH	0.201	0.545	0.126	

DO	0.1	0.56	-0.342	
Turbidity	0.174	-0.422		-0.629
Conductivity	0.379		-0.207	-0.162
N-NO3	0.292	0.225	0.274	-0.539
TSS	0.101		0.784	0.279
Mg	0.379	-0.164	-0.19	0.24
K	0.34	-0.145		0.274
Ca	0.393	-0.107	-0.182	0.232
Sr	0.384	-0.146		0.114
Ba	0.345	0.261	0.225	

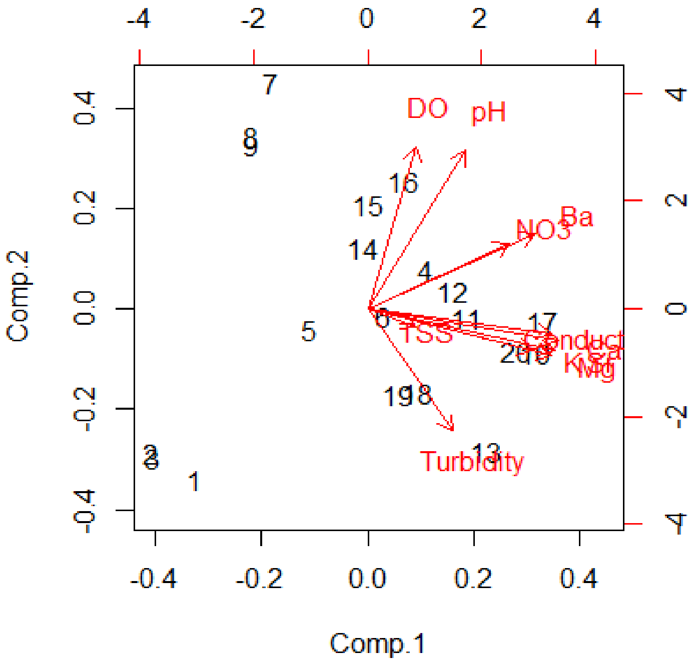

Figure 4. Coordinates of principal component axis (PC 1 and PC2) based on the monitored variables and sampling sites (sites 1-6, 10 – 12, and 17 – 19 associated to Irish Creek; site 7 – 9 and 14 – 16 associated to Leesville Lake; site 13 and 20 associated to Connotton Creek).

Correlation coefficients calculated by the Pearson method reveal the linear correlations between variables. As coefficient values close to 1 or -1, highly positive or negative correlations are present, and values close to zero indicate random relationships between variables. Table 6 presents the matrix of Pearson coefficients for correlating landscaping parameters (rows) to water quality parameters (columns). A strong positive correlation (coefficient values close to or above 0.9) was observed between metals and the developed land percentage. A strong correlation with an increase in well pads suggests their migration, perhaps through runoff and transport of the sediments. A strong correlation between the turbidity and forest patch number suggests greater erosion and transport of sediment from the well pads to the Irish creek and Leesville Lake. The correlation between nitrate and forest patch number is slightly lower with a coefficient value of 0.79 but is still significant. Moderately negative correlations (- 0.354 to – 0.574) are reported between metals and the percentage of forest land. Moderately positive correlations are also observed between nitrate and developed land percentage.

Additionally, weak to moderate negative correlations between water quality parameters and well pad density is present. Turbidity and nitrate are primary water quality parameters associated with changes in the landscape. An increase in runoff from the well pads contributed to higher turbidity in Irish creek and Leesville Lake. Excess runoff is possible with observed increases in the developed land and an increase in the forest patch number suggesting forest fragmentation due to the construction of impervious well pads, access roads, and oil and gas pipeline ROWs.

Table 6. Pearson correlation coefficient for landscaping parameters and water quality.

Landscaping Parameters	DO	Turbidity	Conductivity	N-NO_3	TSS	Mg	K	Ca	Sr	Ba
Forest %	0.479	-0.462	-0.470	-0.37	-0.201	-0.482	-0.354	-0.431	-0.574	0.133
Agriculture %	-0.448	-0.189	0.213	-0.183	0.111	0.141	0.095	0.176	0.261	-0.238
Developed %	-0.019	0.232	0.827	0.532	-0.030	0.948	0.652	0.887	0.897	0.032
Well Pad Density	-0.378	-0.285	-0.611	-0.183	0.073	-0.484	-0.499	-0.570	-0.317	0.094
Number of Forest Patch	-0.173	0.896	0.053	0.710	0.021	0.153	0.258	0.048	0.110	0.116

6. Conclusions

The project is successful in retaining and graduating undergraduate students enrolled in minority schools primarily serving under representative populations. Throughout the engagement in research work, students were observed to perform better in their academic studies. Meanwhile, this study assessed the impact of increased oil and gas exploration and development from the Utica shale deposits during the recent boom in eastern Ohio on the local landscape, forest fragmentation, and water quality in streams and lakes. Instead of mixing oil and gas activity with other land uses across the counties, a unique drainage basin approach identified small drainage areas that exclusively captured the activity in terms of well pads and auxiliary access roads and water storage areas. The oil and gas activity in terms of production, areas, and well pad density were quantified during the boom period in the drainage areas delineated for each sampling site in the headwater areas of Tuscarawas subbasin in eastern Ohio. Water quality of the selected surface water was monitored over two a two year period. Ca, Mg, Ba, and Sr typically found in flow back waters from wells were also present in the collected surface water samples with low concentrations. Between 2013 and 2019, a maximum of 4.5% area increase was observed in developed land in the delineated areas that are suspected to caused by well pad construction, which is insignificant compared to the overall basin area. Minor to no fragmentation was observed for forest land within the studied sub-basins. Slight increases in turbidity, metals found in brine, and nutrients were observed in Irish creek closer to its headwaters, where intense drilling and production of oil and gas occurred. Greater erosion of sediments across impervious well pads, auxiliary areas, and surrounding fragmented forest contributed to minor changes in water quality in the Irish creek and Leesville sub-watersheds. The development of well fields in higher elevations within secluded forested lands in eastern Ohio, upstream of water bodies, is feasible since it does not significantly impact the mixed forest and agricultural lands or the water quality in the remainder of the sub-basins.

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