© 2018 IJSRST | Volume 4 | Issue 5 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

Environmental Impact of Hydraulic Fracturing (HF) using Spatial Analysis, Bradford County, Pennsylvania

James McClain, MSc, Doctoral Candidate
Department of Environmental & Occupational Health; School of Public Health Indiana University Bloomington

ABSTRACT

Hydraulic fracturing (HF) posed an environmental risk to surface water and groundwater quality. Population relies on the quality of water for basic needs. The objective of the study is to use cluster spatial and slope analysis to determine the HF impact in Bradford County, Pennsylvania environments. Spatial cluster produces an array of fundamental public health questions relating to the effects of HF on the environment. The slope analyzes the elevation of HF to surface water and groundwater. Base on the increase of HF activities, the surface water, and groundwater may be polluted from spill, leakage, and intrusion of fracking fluid. The geospatial information data for the study were collected from the United States Geological Survey (USGS), PA Department of Environmental Protection (PADEP), and the National Bureau of Census. The methods used to analyze the data to determine the spatial cluster in the environment are spatial autocorrelation (Moran's Index), Hotspot analysis (G statistic), Cluster and Outlier analysis (Anselin's Local Moran's Index) and the Empirical Bayesian Kriging. The results were interpreted from high or low G statistic, Moran's Index value, Z-score, and p-value. Pennsylvania Moran's Index 0.29, and Z-score, p-value (37.9, 0.0001) indicate a tendency toward clustering a statistically significant. A positive G statistic & large Z-score indicate a more intense clustering of areas of high values – hotspot and a significantly smaller negative G statistic & Z-score indicates more extreme low values – cold spot. Therefore, Albany, Wilmot, Overton, Terry, and Monroe municipalities have high positive G-statistic and statistically significant ($p < 0.05$) Z-values indicating hot spot of hydraulic fracturing operation in the county.

Keywords: Pennsylvania, Hydraulic Fracturing, Spatial Analysis, Geostatistical Analysis, Kriging, Hotspot Analysis, Moran's Index

I. INTRODUCTION

Hydraulic fracturing (HF) or "fracking" is one of several different reservoir stimulation methods used in the United States to increase oil and gas production from low-permeability reservoirs found in fine-grained sedimentary rock (such as tight sands, coal beds, and shale) [1]. The fracking process is used to remove natural gas or oil that is trapped in shale formations [2]. There are 48 shale gas basins around the world in about thirty countries containing about 70 shale formations. There are two significant shale formations in the United States, the Barnett Shale in Texas and the Marcellus Shale in the northeast. The Marcellus Shale contains a black shale that holds trace levels of a radioactive substance that can create an environmental hazard [3] when released during fracking actives. Using regression analysis, the U.S. Energy Information Administration predicted that shale gas would account for almost 50 percent of the national domestic natural gas production by 2030 [4].

HF is divided into two types, vertical and horizontal drilling. Horizontal drilling/fracking has transformed the economy of the U.S. petroleum industry since its adoption [5]. The horizontal drilling extends within the petroleum-bearing rock strata resulting to more significant exposure of the wells bore to recoverable oil [6]. In the United States, reservoirs undergo HF typically at depths of 6,000 to 10,000 feet [7].

An unconventional gas well is a borehole drilled or being drilled for or to be used to produce natural gas from an unconventional formation. Unconventional formation is a geological shale formation existing below the base of an overlying stratum (e.g., the Elk Sandstone, in the case of the Marcellus Shale), where natural gas generally cannot be produced at economic flow rates or in commercial volumes by conventional means. In these cases, vertical or horizontal wellbores stimulated by hydraulic fracture treatments, or multilateral wells bores or other techniques to expose more of the formation to the wells bore, are used.

HF involves injecting a "slurry," a mixture of fracking fluid and proppants, into a subsurface petroleum reservoir under high pressure. Injection creates and holds small open fractures, about as wide as one or two grains of sand. When the infusion is stopped, and the high pressure is reduced, the formation attempts to settle back into its original configuration, but the proppants keeps the fractures open. The open fractures allow hydrocarbons such as crude oil and natural gas to flow from the rock formation back to the wellbore and then to the surface [8].

The efficiency of HF processes are enhanced by the addition of a mixture of chemicals (additive) to the fracking fluid whose functions comprise (1) dissolving minerals and aiding in crack formation, (2) reducing bacteria growth, (3) restricting fluid loss, and (4) reducing friction in the fissures [8]. The additive typically includes from three to twelve chemicals, used in concentration making up 0.5 to 2 percent of the total injected liquids, the remainder being water [7].

1.1 Significance of HF

HF is significant economically [9] due to the considerable increase in oil and gas recovery achieved [10]. The dramatic rise in oil prices in the decade starting in 1998 was fundamental to the high exploration of unconventional shale using hydraulic fracturing [3]. Between 2008 and 2014 gas produced through fracking rose to 26 trillion cubic feet [11].

The American Oil and Gas Reported estimated that as many 90% of all wells in the U.S. have been fractured and 30% of the natural gas reserve is recoverable [12]. In 2011, the National Petroleum Council reported that HF accounted for more than 43% of total U.S. oil production and 67% of natural gas production at the time [10].

1.2 Heath Impact

HF impacts are manifest in a variety of manner on ecosystems and organisms, with both short- and long-term effects which may differ in scope and magnitude [13]. To date, assessments of environmental impact have mostly focused on water quality issues, and less on air and soil pollution.

Some of the slurry additives have a toxic effect. However, toxicological data are limited regarding most additives, and not all degradation pathways and products of reactive additives are known [13].

During HF operations, chemicals spilled as well as methane gas has been released into the environment [2]. Wastewater or the flow back typically has a high concentration (~35g/L) of total dissolved solids, with salinity ranging from 50g/l to 157g/l [14]. The threat of contaminating groundwater and wells water is a significant consideration because of its potential immediate impacts as well as long-lasting consequences [10].

A report from the Public Health England's center for radiation, chemical, and environmental health emphasized that HF contaminate groundwater level, but previous reports indicated that surface water is more exploring to contamination as compared to groundwater [15]. The volume of the flow back has been reported to vary from 1500 m^3 to 4500 m^3 per well per week but decreases with time upon the completion of fracking operation [14]. Emergency situations such as blowouts, chemical spills from sites with hydraulic fracturing, or discharges from the transportation of materials associated with HF (either to or from the wells pad) could potentially jeopardize public safety.

1.3 Statement of Problems

The rapid development of unconventional sources of oil and natural gas using HF has generated considerable controversy. Supporters have argued that fracking will spur economic growth, lead to more secure domestic energy supplies, and facilitate a rapid transition away from carbon-intensive coal-based electricity generation. Opponents have focused on potential adverse impacts on public health, the environment, and communities near the energy sources [16].

Research has failed to support claims that HF is associated with drinking water sources contamination [17]. There has not been adequate multidisciplinary research to substantiate whether HF has a severe environmental impact.

Therefore, the purpose of the research is to assess the impact of HF on the environment in community Bradford County, Pennsylvania (PA), from geospatial datasets downloaded from United States Geological Survey and Pennsylvania Department of Environmental Protection using ArcGIS version 10.5.

The central hypothesis is that Hydraulic Fracturing operations impact the environment in Bradford County, PA.

The objectives are (1) to spatial correlate HF dataset and sinkhole or watershed using cluster analysis and Moran I. (2) to identify the degree of risk associated with HF of residents within 50 – meter buffer zone of Bradford County using hotspot analysis. (2) To explore and predict spatial patterns of HF on groundwater or surface water in Bradford County using Kriging, hotspot and Moran I analysis.

II. METHODS AND MATERIALS

2.1 Research Setting

The study location is Bradford County, Pennsylvania. One of the expanded occupations between 2005 to 2010 in Pennsylvania was HF with an increase from 4 deep wells to 1386 deep wells [18]. Natural gas processing in the state grew more than five-fold from 2010 to 2014. In 2015 production of natural gas increased eight times because of the Marcellus Shale. The production exceeded 4.7 trillion cubic feet ranking the state second in the nation, after Texas [19]. There are several HF industries in Pennsylvania, but the Chesapeake Appalachia LLC industries currently operate in Bradford County, Pennsylvania rank the highest production of natural gas in the state. Chesapeake Appalachia LLC produced more than 2 billion cubic feet of natural gas per day in the state. The industrial has approximately 3,300 employees with 7.8 billion in revenue[20].

2.2 Materials

The datasets (Appendix I) used for the research were downloaded from the Pennsylvania Department of Environmental Protection (PADEP), the United States Geological Survey Map Viewer, and the United States National Census Bureau. The dataset downloaded from PADEP includes the active unconventional HF and the Natural Lands Trust dataset. The dataset was cleaned used to clip out the Chesapeake Appalachia LLC HFGIS data to analyze the environmental impact on Bradford County, Pennsylvania.

The dataset from the United States Geological Services (USGS) includes the National Hydrologic Dataset (NHD) and National Land Cover Dataset (NLCD). From the United States Census Bureau, the TIGER shapefile for Pennsylvania and the Block Census for Bradford County was downloaded.

2.3 Analytical Methods

Clustering analysis was performed on the geological dataset of the HF locations in the study site using the following spatial tools in ArcGIS version 10.5; kriging, cluster and outlier analysis (Anselin's Local Moran Analysis), hotspot analysis and the Spatial autocorrelation – Moran's Index. These tools were used to explore the pattern of the HF and impact on the environment. The environmental issues associated with the HF were a population of families within 50-meter buffer zone of the HF site and watershed. Other environmental concerns were a sinkhole, groundwater and surface water.

a. Empirical Bayesian Kriging (EBK)

Empirical Bayesian Kriging (EBK) is a modern mapping method, which accounts for the uncertainty of parameter estimates in functions describing the changes in property variance with increasing the survey area (variograms) [21]. EBK accounts for the error by calculating the semi-variogram. The EBK analysis used to predict environmental hazard.

b. Cluster and Outlier Analysis

Cluster analysis identifies subgroups within a dataset that resemble other items within the subgroup. For this research, a cluster is an area with a high concentration of HF relative to other areas in Bradford County, Pennsylvania. Cluster analysis identified cases [22] and characterized the distribution [23] of the Chesapeake well pads.

c. Hotspot Analysis

Hotspot analysis is used widely for both academic and applied purposes, including the areas of geology and public health and epidemiology. Hotspot offers insight into the existence of naturally occurring conditions versus epidemics or environmental concerns.

Hotspot analysis was used to identify the relatively high proportion of Systemic Lupus Erythematosus cases among Chinese in greater Toronto areas [24]. The hotspot analysis for this study compares HF relative to the watershed, groundwater, and population within 50-meter buffer zone.

d. Spatial Autocorrelation – Moran's I

The spatial autocorrelation or Global Moran's I am an inferential statistic tool with results interpreted within the context of the null hypothesis, that the attribute (hydraulic fracturing) analyzing is randomly distributed among features in the study area, suggesting that HF not be associated with environmental concern. The Moran's Index uses the Getis-Ord and G^* statistic to verify the null hypothesis. In a study to identify trends in tourist movement in Europe, the G-statistic revealed a concentration of high values with very high statistical significance in the selected sites indicating spatial autocorrelation [25]. High G^* statistic values would indicate the presence of geographical clusters of HF among the neighborhood where the Chesapeake Appalachia LLC. operates in Bradford County, Pennsylvania.

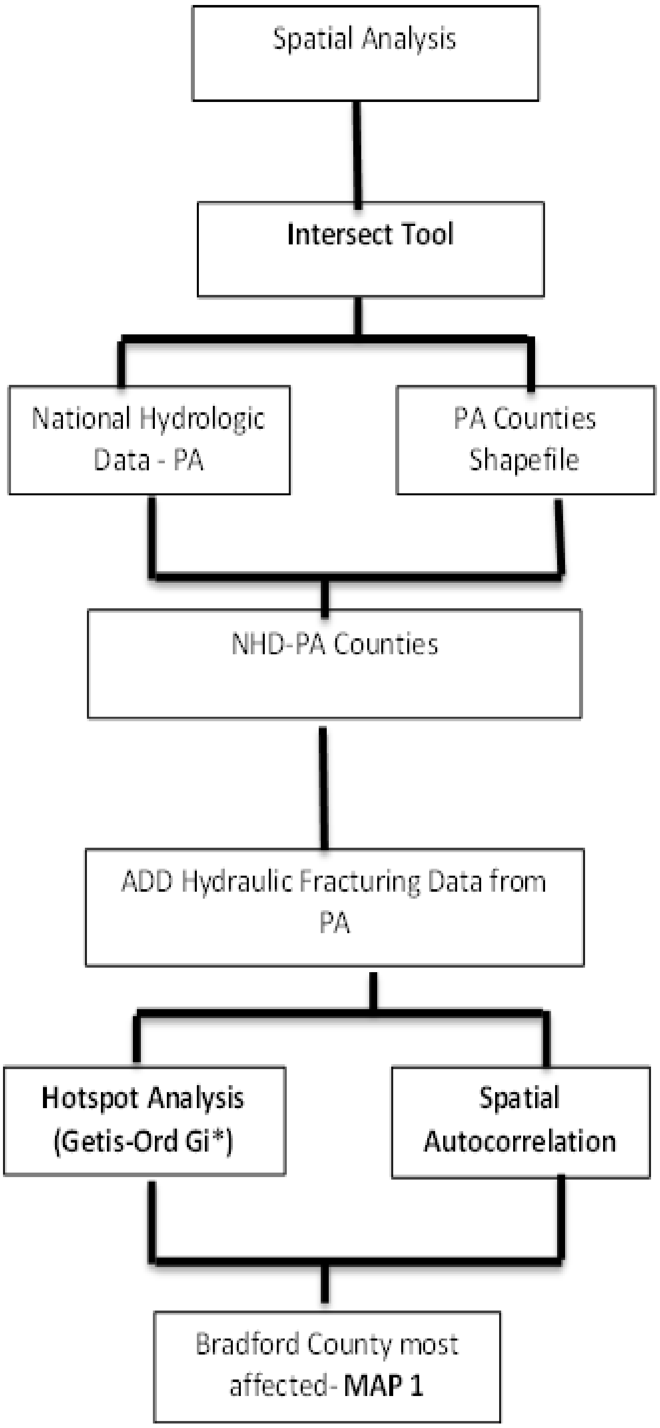
A positive G^* statistic depicting a large cluster of HF in the neighborhood would indicate a high prevalence of environmental hazard. The goals of the spatial clustering analysis are (1) to provide innovative ways to gain insights into the likelihood that such incidence would occur by chance, and (2) to prioritize areas for further investigation.

e. Slope

Slope measures the steepness or the degree of the inclination of hydraulic fracturing relative to the surface water, groundwater, and public water supply in Bradford County.

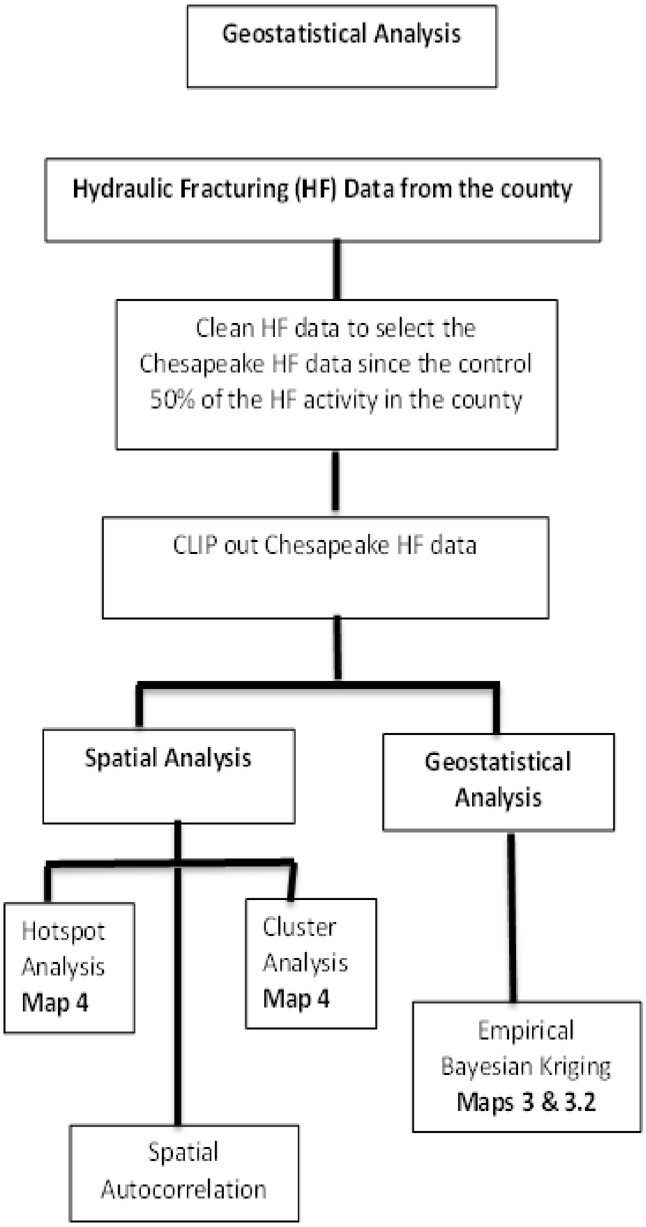
Procedures

Step I Pennsylvania, PA Hydraulic



Step II Hydraulic Fracturing analysis in Bradford County, PA

Details of these procedures are presented in Appendix 3.



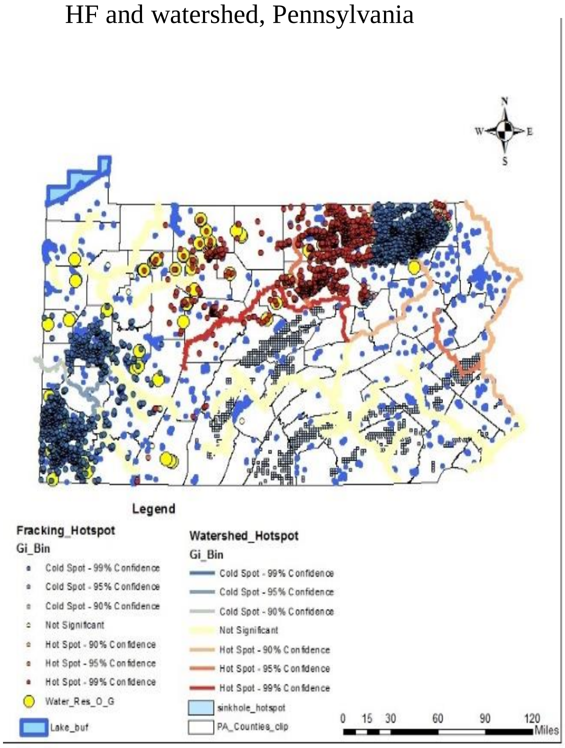
III. RESULTS

Pennsylvania

The spatial hot spot analysis and Moran's Index were the tools used to analysis HF GIS dataset of Pennsylvania. The result was Map 1.

The hotspot analysis provides information on the cluster of the hydraulic fracturing activities in the state of Bradford county most affected. Spatial autocorrelation was used to determine the Moran's Index (Figure 1). The Moran's Index produced a positive value of 0.29 with Z – score of 37.8 and p-value< 0.0001 at 95% confidence level, thus statistically significant.

Map 1: Comparing Hotspot analysis of HF and watershed, Pennsylvania



Bradford County

Map 1 results show that hydraulic fracturing (HF) in Bradford County, PA is clustered. There are approximately 1,097 active HF wells in Bradford County operated by the Chesapeake Appalachia LLC (CAL) and the Talisman Energy. However, the analysis of HF in the county was based on GIS data from the Chesapeake Appalachia LLC (CAL) operational site. The CAL GIS dataset was extracted from state HF database of PA using selection by attribute in ArcGIS version 10.4.

In Bradford County, the CAL owns approximately 50% of the active HF wells and has committed 281 environmental violations. The CAL dataset in the county was analyzed using the Moran's Index and Getis-Ord spatial tools. The Getis-Ord statistic provides more intuitive results and better visual investigation, with the advantage of distinguishing high-value clusters from low-value clusters [26].

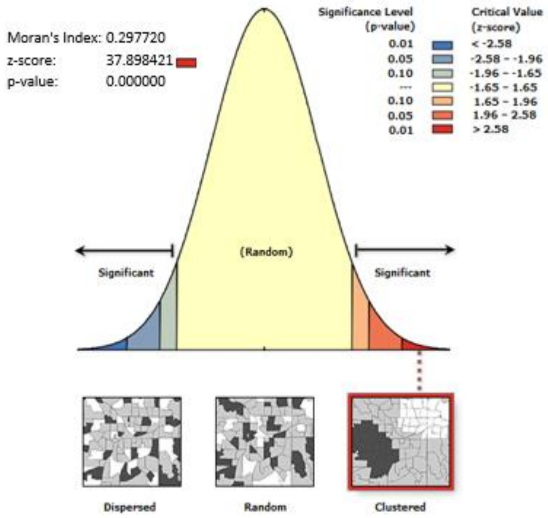


Figure 1. Moran's Index (0.29) of hydraulic fracturing, Pennsylvania

Table 1, presents the results from the Getis-Ord Global statistic (hotspot analysis). Table 1 calculates the G statistic, the Z-score, and p-value from the Moran's Index (spatial autocorrelation) of CAL wells pads in the county.

Table 1. Municipality Hydraulic Fracturing, Bradford County, Pennsylvania

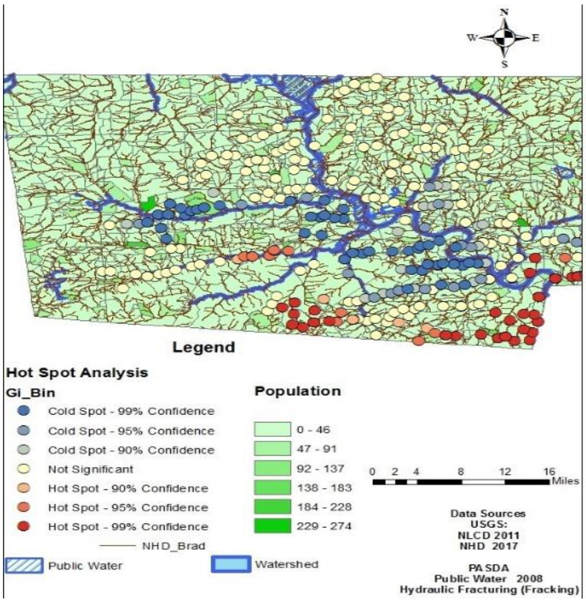
MUNICIPALITY	Permit Issue Day	WELL PAD	Z - Score	P - Value	G^* Statistic
Albany	5/23/2013	145323	4.26	10^{-3}	3
Wilmot	3/22/2014	145632	3.86	10^{-3}	3
Overton	4/4/2014	147534	3.42	10^{-3}	3
Terry	10/11/2011	147536	4.257	2.E-5	3
Monroe	3/30/2011	148630	1.779	0.075	1
Asylum	1/5/2012	144600	1.507	0.131	0
Leroy	11/25/2010	144952	-0.92	0.355	0
Towanda	2/9/2010	148668	0.144	0.885	0
Franklin	5/9/2013	149090	-1.37	0.171	0
Wells	12/1/2016	149224	0.416	0.677	0
Sheshequin	12/20/2011	149550	1.171	0.241	0
Tuscarora	6/4/2014	144624	-0.63	0.527	0
Wyalusing	6/16/2010	149332	-0.57	0.570	0
Standing Stone	10/23/2010	149368	0.040	0.967	0
Troy	6/24/2011	145669	-2.12	0.033	-1
Canton	6/4/2009	146672	-1.69	0.091	-1
Granville	6/24/2009	149496	-1.68	0.093	-1
Stevens	1/11/2013	150454	-1.91	0.056	-1
Springfield	6/26/2009	147511	-2.012	0.044	-2
West Burlington	8/13/2013	144538	-2.04	0.041	-2
Burlington	1/29/2015	146665	-2.18	0.029	-2
Ulster	1/23/2014	147883	-2.14	0.032	-2
Wysox	9/29/2012	148234	-2.27	0.023	-2
North Towanda	4/4/2014	148409	-2.52	0.011	-2
Herrick	5/28/2015	145352	-2.19	0.028	-2
Litchfield	8/26/2011	145472	-4.29	2.0E-5	-3
Orwell	12/20/2011	149413	-2.83	0.005	-3

Map 2 is the direct product of Table 1. From Map 2, a high clustering of HF is evident in the southern part of the county. The spatial autocorrelation metric, Moran's Index (Figure 2), has a Z-score of 16.86, p-value=0.00001, and a positive Moran's Index value of 0.83.

Map 3 depicts the results of the further analysis to predict the impact of the HF on the environment in Bradford County using the Empirical Bayesian Kriging (EBK) method. The EBK function identifies areas of environmental concern associated with HF. In Map 3 an area of environmental concern (orange to red spot) is present in the south of the county, similar to the red circular points depicting hotspot in Map 2. In Map 3, the prediction map was superimposed with the population density map to provide a basic information whether the population within 50-meter proximity is affected by environmental hazard due to HF.

The predictive hotspot (in the red south of County) aligned with the increase in population density (Map 3.2).

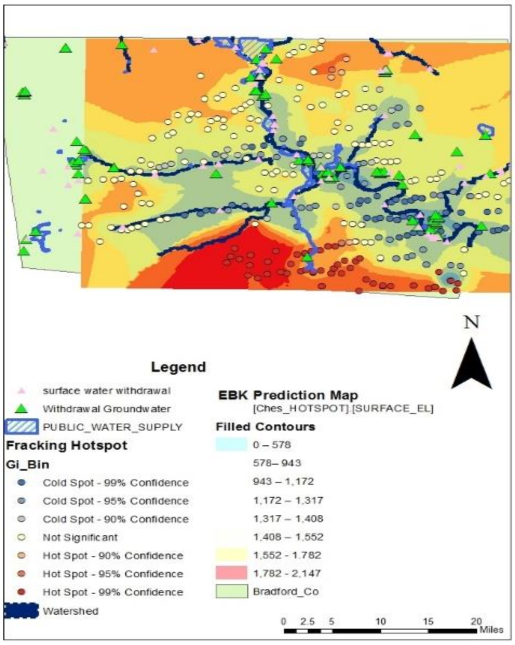
Map 2. Depicting hotspot of HF and the population of Bradford County, Pennsylvania



Another analysis was to predict the exact high or low spots of HF in the county using the cluster & outlier analysis known as the Anselin's Local Moran Analysis. The cluster & outlier analysis tool identifies a cluster of features with high or low values. The map was labeled in the range of HH to LL which implies from areas of the high cluster to areas of the low cluster, Map 4.

Finally, the slope (Map 5) procedure on the HF in Bradford County was conducted to determine areas of higher elevation relative to surface water; groundwater could contaminate the water body due to intrusion, spill, leakage, and runoff.

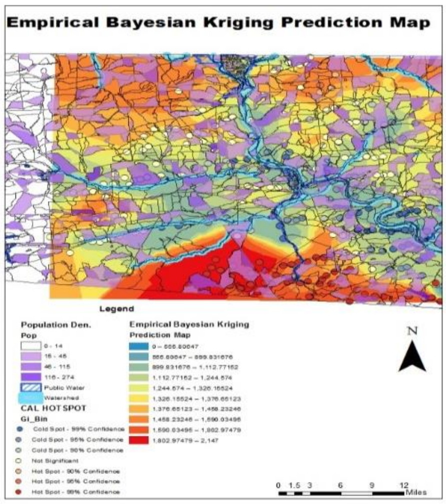
Map 3: The Empirical Bayesian Kriging (EBK) Prediction Map of pollutant associated with HF Bradford County, Pennsylvania



IV. DISCUSSION

The practice of hydraulic fracturing (HF) is considered as either having associated environmental risks (New York Time) or an economic benefit with little information on public health issues (USA Today and the Wall Street Journal) [27]. Economically, HF does create jobs, increases income for land leases, and expands local businesses [16].

Map 3.2 EBK Prediction Map & Population

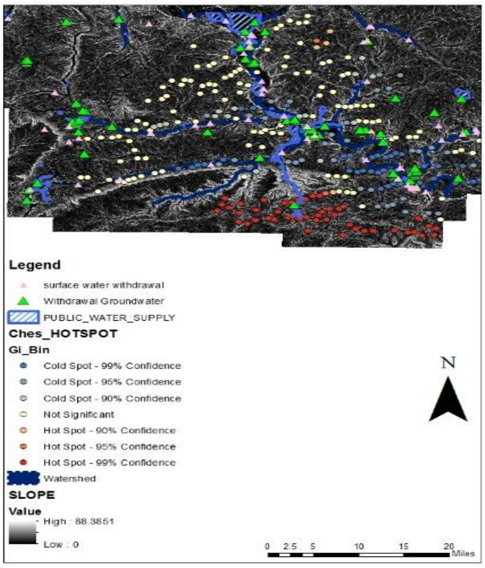


Map 1 hotspot was significant in the north-east of the state, Bradford County being the more affected because of the presence of increased HF sites.

The Moran's Index, 0.29 indicates a tendency toward clustering of hydraulic fracturing (HF) and Z-score, p-value (37.9, 0.0001) (Figure 1) indicates statistical significance. Therefore, there is less than 1% likelihood that the observed pattern associated with HF in Pennsylvania could have occurred by chance. The more affected county with increase cluster of HF in the state was Bradford County.

From Table 1, a statistically significant (p-value < 0.05) positive G statistic & Z-score, the larger the Z-score, the more intense the clustering of high values – hotspot and a significantly smaller negative G statistic & Z-score indicates more exceptional low values – cold spot. Therefore, Albany, Wilmot, Overton, Terry, and Monroe municipalities have high positive G-statistic and statistically significant (p < 0.05) Z-values indicating hot spot of hydraulic fracturing operation in the county. In the U.S. volume of water used per well for the HF differ per states. The volume of water used per wells in Pennsylvania between 2.3 to 6.6 million gallons[28]. About 240,000 gallons (nearly 8% of the injected volume) of fluid flow-back at an estimated average rate of 34,000gal day^{-1}per wells [29] collected. The flow-back water produced within relatively few days of the hydraulic fracturing. The total dissolved solids concentration of the flow-back water is approximately 10,000ppm about 10% salinity[8].

Map 5: Slope Analysis of the Chesapeake HF in Bradford County, PA



The project used spatial analysis to examine clustering of HF in Bradford County and its association to an environmental hazard. The Chesapeake Appalachia LLC industrial is the most dominant HF industrial in Bradford County, Pennsylvania, and all spatial analysis was calculated on the GIS of active wells pad in the county. A spatial agglomeration of environmental pollution [26] associated with HF in the Bradford municipality may increase because of the high G Statistic of Spring to Orwell municipalities with a tendency toward clustering.

Further analysis conducted on the HF in the county was the Anselin's Local Moran I. the Anselin's Local Moran I spatial statistics identify clusters of features with values similar in magnitude. A high positive Z score for a wells pad (Table 1) indicates that the surrounding well pads have similar values either high or low values. The CO-Type field in the Anselin's spatial tool indicates HH and LL (Map 4, Appendix 2) for a statistically significant (p-value < 0.05) (Table 1) cluster of increase (high) and low (cold) HF activities respectively.

A low negative Z-score for a statistically significant (Table 1) indicate a spatial outlier of HF. However, the Anselin's CO-Type further interprets the spatial outlier as HF with increase activities surrounded by features with low values (HL) or low values features surrounded by increase HF operation (LH) (Map 4, Appendix 2).

The HH meaning indicates that the neighboring municipality all have high percentages of exposure to environmental health hazard associated with HF whereas the LL explain the association of neighboring municipality exposure to low percentages of environmental hazard.

A 2011 opinion poll survey conducted in Pennsylvania showed that 48% accepted natural gas drilling (Hydraulic fracturing), 40% accepted the economic impact in the state, 33% concerned about the environmental hazard. However, the overall results showed that 50% expect more economic benefits than problems, 32% more problem than benefits and 17% problem and benefit at equilibrium[16].

V. CONCLUSION

All maps showed a high cluster of HF associated with environmental hazard due to hydraulic fracturing. The analysis of HF in Albany, Wilmot, Overton, Terry, and Monroe municipalities of Bradford County, Pennsylvania was statistically significant of the environmental impact of HF operations. It implies the measurement of the probability values that the likelihood of the population within the high cluster area of the municipalities could be exposed to a hazardous environmental pollutant that may be associated with HF.

The study provides limited evidence that environmental pollution in the municipalities is associated with hydraulic fracturing. Further studies on the validation or analysis of biomarkers of the individual in operation are significant. The biomarkers could provide information if an individual were exposed to chemical use during hydraulic fracturing.

The testing of groundwater and surface water to estimate the impact of HF and assessment of co-contaminant in soil within 50-meter proximity of fracking site could provide scientific evidence on the impact of HF.

The conduct of the survey may involve multi-disciplinary individual from Environmental Health, Environmental Science, Geology, physicians, and epidemiology. The objectives of the further research could be to conduct on water and soil sampling and testing on the field and laboratory analysis, as well as the use of survey questionnaire to capture health history before and at the time of the exploration process of oil.

Finally, results from Bradford County indicates that cluster of Hydraulic Fracturing operation needs immediate attention, especially in the most affected municipalities. Defining the impact of hydraulic fracturing on the environment and human is fundamental is associated with quality health.

VI. REFERENCES

[1]. Gallegos, T.J. and B.A. Varela, Data Regarding Hydraulic Fracturing Distributions and Treatment Fluids, Additives, Proppants, and Water VolumesTreatment Fluids, Additives, Proppants, and Water Volumes Applied to Wells Drilled in the United States from 1947 through 2010. 2015, USGS: Virginia.

[2]. Carlton, A.G., et al., The Data Gap: Can a Lack of Monitors Obscure Loss of Clean Air Act Benefits in Fracking Areas? Environmental Science & Technology, 2014. 48(2): p. 893-894.

[3]. Benavides, P.T. and U. Diwekar, Optimal design of adsorbents for NORM removal from produced water in natural gas fracking. Part 1: Group contribution method for adsorption.

Chemical Engineering Science, 2015. 137: p. 964-976.

[4]. Sovacool, B.K., Cornucopia or curse? Reviewing the costs and benefits of shale gas hydraulic fracturing (fracking). Renewable & Sustainable Energy Reviews, 2014. 37: p. 249-264.

[5]. McDivitt, H., Hydraulic Fracturing: What it is used; Why all the fuss? Is it used in Indiana. 2013.

[6]. Helms, L., Horizontal Drilling: North Dakota Survey. 2008. 35(1): p. 1-3.

[7]. FracFocus, Chemical use in Hydraulic Fracturing. 2013.

[8]. Batley, G.E. and R.S. Kookana, Environmental issues associated with coal seam gas recovery: managing the fracking boom. Environmental Chemistry, 2012. 9(5): p. 425-428.

[9]. Montgomery, C.T. and M.B. Smith, Hydraulic Fracturing history of an eduring technology. Journal of Petroleum, 2010: p. 26-41.

[10]. Zuppann, C.W. and J.C. Steinmetz, Hydraulic Fracturing: sn Indiana Assessment. 2015: p. 35-45.

[11]. Wu, K.Q., et al., Transition to sustainability with natural gas from fracking. Sustainable Energy Technologies and Assessments, 2016. 14: p. 26-34.

[12]. Fisher, K., Data confirm safety of well fracturing: The Americal Oil & Gas. 2010.

[13]. Burton, G.A., et al., Hydraulic "Fracking": Are Surface Water Impacts An Ecological Concern? Environmental Toxicology and Chemistry, 2014. 33(8): p. 1679-1689.

[14]. Altaee, A. and N. Hilal, Dual-stage forward osmosis/pressure retarded osmosis process for hypersaline solutions and fracking wastewater treatment. Desalination, 2014. 350: p. 79-85.

[15]. Torjesen, I., Fracking poses little risk to public health, but evidence is limited. Bmj-British Medical Journal, 2013. 347.

[16]. Boudet, H., et al., "Fracking" controversy and communication: Using national survey data to understand public perceptions of hydraulic fracturing. Energy Policy, 2014. 65: p. 57-67.

[17]. Tuller, D., As Fracking Booms, Dearth Of Health Risk Data Remains. Health Affairs, 2015. 34(6): p. 903-906.

[18]. Smith, M.F. and D.P. Ferguson, "Fracking democracy": Issue management and locus of policy decision-making in the Marcellus Shale gas drilling debate. Public Relations Review, 2013. 39(4): p. 377-386.

[19]. EIA, U.S., Pennsylvania State Energy Profile. 2016, U.S. Energy Information Administration.

[20]. Chesapeake, Operation Reports, Pennsylvania. 2016, Chesapeake Energy.

[21]. Samsonova, V.P., Y.N. Blagoveshchenskii, and Y.L. Meshalkina, Use of Empirical Bayesian Kriging for Revealing Heterogeneities in the Distribution of Organic Carbon on Agricultural Lands. Eurasian Soil Science, 2017. 50(3): p. 305-311.

[22]. Chandler, R.E., et al., Current Safety Concerns with Human Papillomavirus Vaccine: A Cluster Analysis of Reports in VigiBase (R). Drug Safety, 2017. 40(1): p. 81-90.

[23]. Fazio, C., et al., Analysing the Conceptions on Modelling of Engineering Undergraduate Students: A Case Study Using Cluster Analysis. Key Competences in Physics Teaching and Learning, 2017. 190: p. 79-94.

[24]. Al-Maini, M., et al., A Hot Spot for Systemic Lupus Erythematosus, but Not for Psoriatic Arthritis, Identified by Spatial Analysis Suggests an Interaction Between Ethnicity and Place of Residence. Arthritis and Rheumatism, 2013. 65(6): p. 1579-1585.

[25]. Garcia-Palomares, J.C., J. Gutierrez, and C. Minguez, Identification of tourist hot spots based on social networks: A comparative analysis of European metropolises using photo-sharing services and GIS. Applied Geography, 2015. 63: p. 408-417.

[26]. Ding, L., et al., Spatial-Temporal Hotspot Pattern Analysis of Provincial Environmental Pollution Incidents and Related Regional Sustainable Management in China in the Period 1995-2012. Sustainability, 2015. 7(10): p. 14385-14407.

[27]. Blair, B., T. Heikkila, and C.M. Weible, National Media Coverage of Hydraulic Fracturing in the United States: Evaluation Using Human and Automated Coding Techniques. Risk Hazards & Crisis in Public Policy, 2016. 7(3): p. 114-128.

[28]. EPA, U.S., Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States. 2016, U.S. EPA: Washington DC.

[29]. Brownlow, J.W., S.C. James, and J.C. Yelderman, Influence of Hydraulic Fracturing on Overlying Aquifers in the Presence of Leaky Abandoned Wells. Groundwater, 2016. 54(6): p. 781-792.

Appendix 1 Database Table

Full Title	**Brief Description**	**Scale**	**Publication**	**Originator**
Oil & Gas Locations - Unconventional	The following data set contains all the Oil & Gas Wells in Pennsylvania that the Dept. of Environmental Protection has locational information on.	1:24,000	2017/02/11	Pennsylvania Department of Environmental Protection
National Hydrologic Data (NHD)	The NHD contains reach codes for networked features, flow direction, names, and centerline representations for areal water bodies/watershed of Pennsylvania. The hydrographic feature names contained in and displayed by the NHD are extracted and validated from the Geographic Names Information System (GNIS).	1:24,000	2016/11/07	USGS
National Land Cover Data (NLCD)	There are 15 categories of land use shown in the dataset. The NLCD products are created through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium.	1:24,000	2011/02/16	USGS
Decennial Block Census for Bradford county	The census dataset from the Bradford county contains Age, Race, Housing.	1:100,000	2010	National Census Bureau
National Elevation Data (NED)	This tile of the NED is 1/3 arc-second resolution. The NED serves the elevation layer of The National Map and provides basic elevation information for earth science studies and mapping applications	1:24,000	2016-07-28	USGS

	in the United States.			
Water Resources	A Water Resource is a DEP primary facility type related to the Water Use Planning Program and the sub-facility include: Discharge, groundwater withdrawal, interconnection, storage, surface water withdrawal, water allocation.	1:24,000	2017/04/16	PADEP
Digital data set of mapped karst features in south-central and southeastern Pennsylvania	This point dataset represents an (incomplete) inventory of karst features (herein categorized as sinkholes, surface depressions, surface mines, or cave entrances) that have been cataloged in Pennsylvania.	1:24,000	2007	Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources
PA Counties Boundaries	County boundaries within Pennsylvania as delineated for the PA DOT Type 10 general highway map	1:24,000	2017/01/15	PA DOT, Bureau of Planning and Research, Cartographic Information Division