Health Implications of Hydraulic Fracturing of Water

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Abstract

Hydraulic fracturing is becoming an increasingly prevalent part of today's society, for companies rely on fracking to extract natural gas. However, the contaminants used in the fracturing fluid pose a threat to human health. The contaminants found in fracking water can be grouped into volatile organic compounds, metals, inorganic compounds, dissolved solids, radioactive elements, and microorganisms. The main representative pollutants this paper focuses on are benzene, formaldehyde, arsenic, lead, and various microorganisms. This paper presents a review of literature from several studies highlighting the adverse health effects of these selected contaminants. By ingesting these contaminants collectively, a consumer of fracking water can develop numerous health complications, including cancers, diseases, body system dysfunctions, altered cell processes, and disruption to the genetic code. Consequently, purifying contaminated water before drinking is necessary to sustain a healthy life.

Key Words: fracking, health, cancer, contaminants

Introduction

Water is essential for all living organisms to survive, grow, and develop. Additionally, water has various chemical and physical properties, making water unique from other compounds. Water is regarded as the universal solvent, a solvent that is able to dissolve many different solutes. Moreover, water can form hydrogen bonds with various types of compounds (Knight, Kalugin, Coker, & Ilgen, 2019). Furthermore, pure water exhibits the following physical properties: odorless, colorless, tasteless, and boiling point of 100° Celsius. Humans depend on water to fulfill all cell processes, for water constitutes most of a person's blood. Blood is vital for cells because the red blood cells help move resources, such as nutrients and oxygen, across the human body. Therefore, when someone is dehydrated, fewer nutrients are delivered to the cells, inhibiting cell growth and development. In addition, since water makes up about two-thirds of the body, it is necessary that drinking water should be left unpolluted. Otherwise, contaminants from consumed water would disseminate throughout the bloodstream.

Unfortunately, this essential building block of life is polluted by hydraulic fracturing. Hydraulic fracturing, or fracking, is the process of injecting fluid at high pressure in underground rock formations to obtain natural gas, or methane. In order to increase the pressure needed to disrupt the rock formations and extract natural gas, fracking companies add contaminants to the water, including metals, volatile organic compounds, and inorganic compounds (USEPA, 2020). Because fracking causes the rock formation to rupture, and since the fracking wells often leak, these chemicals can disperse through the fractures and into the water aquifer (USEPA, 2017). The water aquifer is an underground source of water that can be utilized for drinking and irrigation. Thus, since the chemicals in fracking can diffuse into the water aquifer, drinking water can become contaminated. In addition, after the fracking process is complete, some of the fluid flows back to the surface due to internal pressure. However, in most cases, fracking fluid is further injected back into the ground, leading to further contamination (USEPA 2020).

This paper aims to assess the hazard of consuming contaminated water produced at fracking sites. The chemicals in fracking fluid are divided into several groups: dissolved solids, volatile organic compounds, inorganic compounds, and metals. However, for the purpose of this paper, the most lethal chemicals were chosen. Of the volatile organic compounds, benzene was selected to represent the deleterious effects of the aromatic hydrocarbons, or hydrocarbons in the form of a six carbon ring. Aliphatic hydrocarbons, or straight-chained hydrocarbons, constitute volatile organic compounds as well, and formaldehyde was chosen to represent the aliphatic hydrocarbons' health effects. For the metals, both arsenic and lead exhibited numerous carcinogenic properties. Moreover, although fracking fluid does not contain microorganisms, certain microorganisms inhabit fracking sites because these microbes consume the numerous hydrocarbons that are found in fracking water. Therefore, this paper also includes the harmful effects that microorganisms pose to human health. Because hydraulic fracturing introduces volatile organic compounds, metals, and microorganisms into many water sources, fracking leads to adverse health effects in consumers.

Review of Literature

Benzene

One of the detrimental carcinogens in fracking water is benzene, an aromatic volatile organic compound that causes acute myeloid leukemia, immune system dysfunction, and lymphoma. The study *Global Gene Expression Profiling of a Population Exposed to a Range of Benzene Levels* highlights the injurious health effects associated with benzene exposure. In this study, McHale and researchers sampled 250 shoe manufacturing workers who were exposed to benzene as well as 140 controls who were unexposed. The researchers found that benzene interfered with the immune system, specifically B-cell receptor signaling and T-cell receptor signaling. Moreover, the researchers discovered that benzene alters ATP synthesis, and this disruption is especially harmful because cells require ATP for energy to perform specialized cellular tasks. Researchers also found that benzene altered cell apoptosis, or programmed cell death, which can lead to several types of cancer such as acute myeloid leukemia (McHale *et al.*, 2011).

The carcinogenicity of benzene is caused by metabolization, the process where molecules are broken down into energy that cells can use to function (Smith 2010). After benzene is metabolized, benzene's metabolites can disrupt the genetic code by causing chromosomal mutations. Although this genetic disruption is not initially enough to cause leukemia, benzene's metabolites can also cause genetic instability. According to *Advances in Understanding Benzene Health Effects and Susceptibility*, a study was done on mice that proved that metabolites of benzene can cause genetic instability in a similar fashion to ionizing radiation (Smith 2010). Since benzene's metabolites incite further levels of chromosome changes and gene mutations, patients exposed to benzene's metabolites can develop leukemia. Therefore, although benzene exposure initially starts as a single disruption in the genetic code, benzene's genetic instability creates more mutations in a short time period, which is what eventually leads to cancer. Thus, ingesting water that contains benzene, such as water near fracking sites, is harmful to a person's health, for benzene can lead to various disruptions in the genetic code as well as cancer (Smith 2010).

Although most research revolves around the risks of higher levels of benzene exposure, Carugno and collaborators demonstrate that benzene at low levels of exposure leads to negative health effects such as affecting the mitochondria (Carugno *et al.,* 2012). The mitochondria, or the powerhouse of the cell, is vital for cells to obtain enough energy to carry out cellular tasks. Without proper regulation of the mitochondria, the amount of energy being produced can be disrupted. In order to evaluate the mitochondria's condition, researchers examine the blood mitochondrial DNA copy number, or mtDNAcn, which increases whenever mitochondrial DNA has been damaged. Carugno and colleagues perform a study that proves that low-level benzene exposure produces increased mtDNAcn. In Italy, the collaborators held a multicenter cross-sectional study on people exposed to low-levels of benzene and measured the individuals' age, sex, and number of cigarettes a day (Carugno *et al.,* 2012). In Genoa, Carugno and colleagues found a 10.5% increase of mtDNAcn in benzene-exposed individuals in relation to unexposed individuals. In Milan, individuals displayed an 8.2% increase of mtDNAcn when exposed to benzene than when not exposed to benzene. Based on the data, benzene caused the levels of mtDNAcn to increase, which reflects that the patients' mitochondrial DNA has been damaged. Furthermore, the increase of mtDNAcn is associated with a higher risk of developing lung cancer and non-Hodgkin lymphoma (Carugno *et al.,* 2012).

According to *Increased Mitochondrial DNA Cop Number in Occupations Associated with Low-Dose Benzene Exposure,* increased blood mtDNAcn levels are also associated with cells that face oxidative stress (Carugno *et al*., 2012). Oxidation, the process where a substance comes in contact with oxygen, leads to several chemical reactions such as rusting. Oxidation can occur in different forms throughout the human body due to reactive oxygen species (ROS). While ROS is beneficial for the immune system by preventing foreign invaders such as bacteria, an unregulated amount of ROS can also lead to harmful effects in the mitochondria. When cells are exposed to benzene, the amount of ROS increases, leading to damage in the mitochondria. In fact, mitochondrial DNA is especially prone to ROS damage because mitochondrial DNA has a lower amount of protective histones. When cells are impacted with ROS, these cells create more copies of mtDNA in order to compensate for the damage that the ROS has done. While it may seem beneficial that more mitochondria is being produced, this mitochondria continues to be attacked by ROS, causing further oxidative damage and cell death. Moreover, increased mitochondria generates more ROS, and the increase of ROS can induce further oxidative damage to mitochondria. Because more mitochondria is produced, and this produced mitochondria is then targeted by ROS, this cycle damages macromolecules such as lipids, proteins, DNA, and RNA (Carugno *et al*., 2012).

Formaldehyde

Fracking water also includes formaldehyde, an aliphatic hydrocarbon, that causes several types of cancer in the human body. According to the National Cancer Institute cohort, which included over 25,000 formaldehyde-exposed workers in 10 plants, formaldehyde exposure was associated with an increase of nasopharyngeal cancer (Swenberg, Moeller, Rager, Fry, & Starr, 2012). In addition, formaldehyde is an air toxin because formaldehyde increases the risk of adult and childhood asthma and acute respiratory tract illness. Because formaldehyde is highly reactive and soluble in water, 95% of formaldehyde can be inhaled and absorbed within the respiratory tract, mainly affecting the nasal and upper airways. Furthermore, formaldehyde alters pathways that are associated with inflammatory response, cancer, and endocrine system regulation (Rager, Smeester, Jaspers, Sexton, & Fry*,* 2011).

Exposure to formaldehyde can also alter the genetic code in nasal and lung cells due to the chemical's ability to alter microRNA, or miRNA. Not only does miRNA instigate cellular disease, but miRNA also acts as a regulator of gene expression after transcription (Rager *et al.,* 2011). If the amount of miRNA is altered in any way, the alteration can cause numerous health issues such as cardiovascular diseases, cancer, diabetes, and obesity. Additionally, changes in miRNA levels can change the degree of cell apoptosis, cell proliferation (or cell growth) stress response, and metabolism (Adlakha & Saini, 2014). In the study *Epigenetic Changes Induced by Air Toxics: Formaldehyde Exposure Alters miRNA Expression Profiles in Human Lung Cells,* formaldehyde was hypothesized to alter miRNA levels (Rager *et al.,* 2011). To verify this hypothesis, Rager and colleagues exposed human lung cells to 1 ppm of formaldehyde and created an environment that imitated the human respiratory tract. Out of the 343 miRNAs assessed for formaldehyde, 89 miRNA demonstrated a decrease in expression. The down regulation of miRNA leads to several types of cancer, including breast cancer and leukemia. Moreover, the down regulation of miRNA can lead to tumors and chromosome loss (Rager *et al.*, 2011).

Arsenic

Along with volatile organic compounds, fracking water contains metals. One prevalent metal in fracking water is arsenic, which can occur in different valence states. Arsenic is typically found in an inorganic form in drinking water, yet this metal is difficult to detect because of the metal's colorless, tasteless, and odorless state (Naujokas *et al.,* 2013). In general, wells in the U.S. contain concentrations of over 3000 μg/L of arsenic. However, according to the United States Environmental Protection Agency (USEPA), the maximum contaminant level for arsenic is 10 μg/L (Naujokas *et al.,* 2013). Furthermore, according to *The Broad Scope of Health Effects from Chronic Arsenic Exposure: Update on a Worldwide Public Health Concern,* the Health Effects of Arsenic Longitudinal Study (HEALS) cohort reported that any concentration of arsenic over 10 μg/L led to 23.5% of chronic disease related deaths and 21.4% of deaths in general. Therefore, there must be very minimal levels of arsenic in drinking water in order for the water to be safe. In fact, arsenic causes several types of cancer, including lung, liver, kidney, bladder, and skin cancer. Arsenic can also cause other immunological, neurological, cardiovascular, respiratory, and dermatological effects. Although these are the most common symptoms, some people may develop skin lesions as well. Arsenic can also lead to adverse health effects on the cellular level. For example, arsenic affects cellular proliferation, cellular signaling, apoptosis, and DNA structure (Naujokas *et al.,* 2013). Arsenic can also alter the genetic code by causing DNA damage, chromosome abnormalities, oxidative stress, and DNA repair (Mo *et al.,* 2009).

By affecting telomerase activity, arsenic induces genetic instability throughout the body (Mo *et al.,* 2009). Telomeres are located at the ends of chromosomes, and the dysregulation of telomere length can cause cancer and aging. As cell division occurs, telomeres shorten, which can lead to cell apoptosis. Telomerase attaches telomeric sequences to the chromosomes' ends when the cell divides, preserving the amount of chromosomes. Most normal cells have minimal or no detectable levels of telomerase activity, but tumor cells express larger levels of telomerase activity. Thus, tumor cells do not exhibit loss of telomere length while the cell replicates. In order to find the relation between arsenic and telomerase levels, Mo and fellow researchers used peripheral blood cells because peripheral blood cells exhibit low levels of telomerase activities and the amount of the human telomerase reverse transcriptase gene (hTERT). The researchers found that the mRNA levels of hTERT increased significantly from 0 to 1 μM of arsenic. However, mRNA levels started to decrease from 2.5 to 10 μM of arsenic. Both an increase and decrease of hTERT levels are injurious to human health. Decreased telomerase activity leads to a lower amount of DNA repair and fragmented chromosomes. Therefore, Mo and researchers infer that hTERT may help with repairing DNA and chromosomes. Although increased levels of hTERT may appear favorable since hTERT would inhibit DNA damage, elevated levels of hTERT can actually lead to several adverse health effects. Since hTERT has the ability to repair DNA, too much telomerase maintenance can allow cancer cells to overcome mortality because hTERT promotes cell growth. Furthermore, many skin cancer cells manifest signs of telomerase, proving that an excess of telomerase is hazardous to human health (Mo *et al.,* 2009).

Lead

Another injurious metal found in fracking water is lead, which can affect both adults and children in severe ways (Sanders, Liu, Buchner & Tchounwou, 2010). Lead impacts several parts of the brain: the prefrontal cerebral cortex (which affects behavior and personality), the cerebellum (which impacts movement and cognitive function), and the hippocampus (which impacts memory). When these pathways are targeted, people can develop brain damage as well as Parkinson's disease, Alzheimer's disease, and schizophrenia. Other neurological disorders induced by lead are convulsions, comas, and decreased muscle coordination. In addition, lead exposure can cause muscle and joint pain in adults. Lead also causes adverse health implications in children, for lead can negatively affect a child's intellectual capacity and behavior. For example, children exposed to lead score lower on intelligence tests and have lower hand-eye coordination and reactive time. According to *Neurotoxic Effects and Biomarkers of Lead Exposure: A Review,* for every exposure to 10 μg of lead, a child loses one to five points on the IQ test. Lead exposure can also instigate hyperactivity in children, a condition that makes paying attention and sitting still more difficult for lead-exposed children (Sanders *et al.,* 2009).

Lead exposure can also disrupt biological functions in the cellular and molecular level (Sanders *et al.,* 2009). Not only can lead initiate cell apoptosis, but lead can also alter the mitochondria and chemical messengers. Additionally, exposure to lead can affect an individual's genes in the brain, liver, and lung. Similar to benzene, lead can generate reactive oxygen species (ROS), a species that plays a crucial role in cell functions such as cell death. However, as previously stated, exceedingly high levels of ROS can be dangerous to a person's health. Lead can also lower the amount of antioxidants in the body; antioxidants are beneficial to the human body by preventing high amounts of oxidation. As lead diminishes the amount of antioxidants, the degree of oxidative stress heightens. Moreover, as ROS levels increase, neurons lose the ability to remove the toxicity from ROS, making neurons especially susceptible to damage (Sanders *et al.,* 2009) .

Microorganisms

In addition to volatile organic compounds and metals, fracking water contains a diverse population of microorganisms. According to Kahrilas and colleagues, several microorganisms in fracking water are *Spirochetes, Clostridia, Synergistetes, Bacteroidetes* and other types of proteobacteria. Furthermore, sulfate-reducing bacteria reside in water near fracturing sites, and this bacteria produces hydrogen sulfide. Because hydrogen sulfide gas can cause corrosion of tubing underground, petroleum and other contaminants are leaked into the groundwater (Kahrilas, Blotevogal, Stewart & Borch*,* 2015). Additionally, fracking water contains methanogens, or microorganisms that produce methane. Some methanogens include *Archaea, Halomas,* and *Marinobacter* (Mouser, Borton, Darrah, Hartsock & Wrighton, 2016). According to *Hydraulic fracturing offers view of microbial life in the deep terrestrial subsurface*, methanogens *Halomas* and *Marinobacter* inhabit fracking sites because these sites contain the aliphatic and aromatic hydrocarbons that enable methanogens to thrive (Mouser *et al.,* 2016).

Although not all microorganisms are toxic, methanogens can induce adverse health implications. For example, methanogens can lead to obesity because these microorganisms are more efficient at breaking down calories. Therefore, since more calories are taken in the body, people can become obese (Chaudhary, Conway, & Schlundt*,* 2018). Furthermore, methanogens can increase the production of fatty acids, adding to the amount of calories being consumed. Methanogens have also been linked to causing inflammatory bowel disease and chronic constipation (Lurie-Weinberger & Gophna, 2015).

Results

Benzene

The study *Global Gene Expression Profiling of a Population Exposed to a Range of Benzene Levels* underscores that benzene interferes with numerous pathways (McHale *et al.,* 2011). In order to determine the significance of each alteration, McHale and collaborators measured the p-value, or the probability value, for each exposed pathway. The p-value assesses the probability of the null hypothesis, or the hypothesis that there will be no significance when a variable is altered. In this case, the null hypothesis is that benzene does not significantly interfere with various pathways. If the probability of the null hypothesis is less than 0.05, the null hypothesis can be rejected. As shown by Figure 1, the p-values for each pathway are less than 0.05, meaning that the alternate hypothesis, which is that benzene does alter several pathways, is significant. However, the only exceptions to having a p-value less than 0.05 are at low levels of benzene for protein export (p-value = 0.053) and at high levels of benzene for insulin signaling pathway (p-value = 0.052).

Figure 1: P-Value of Pathways Altered by Benzene in Relation to Exposure

	Benzene exposure category			
Pathway name[a]	Very low ($n = 29$)	Low ($n = 30$)	High ($n = 11$)	Very high ($n = 13$)
Chronic myeloid leukemia	0.034	0.033		
Pancreatic cancer	0.023	0.007		
Oxidative phosphorylation[b]	< 0.001	0.003	0.001	
Small-cell lung cancer[b]	0.004	0.002	0.027	

	Benzene exposure category			
Pathway name[a]	Very low ($n = 29$)	Low ($n = 30$)	High ($n = 11$)	Very high ($n = 13$)

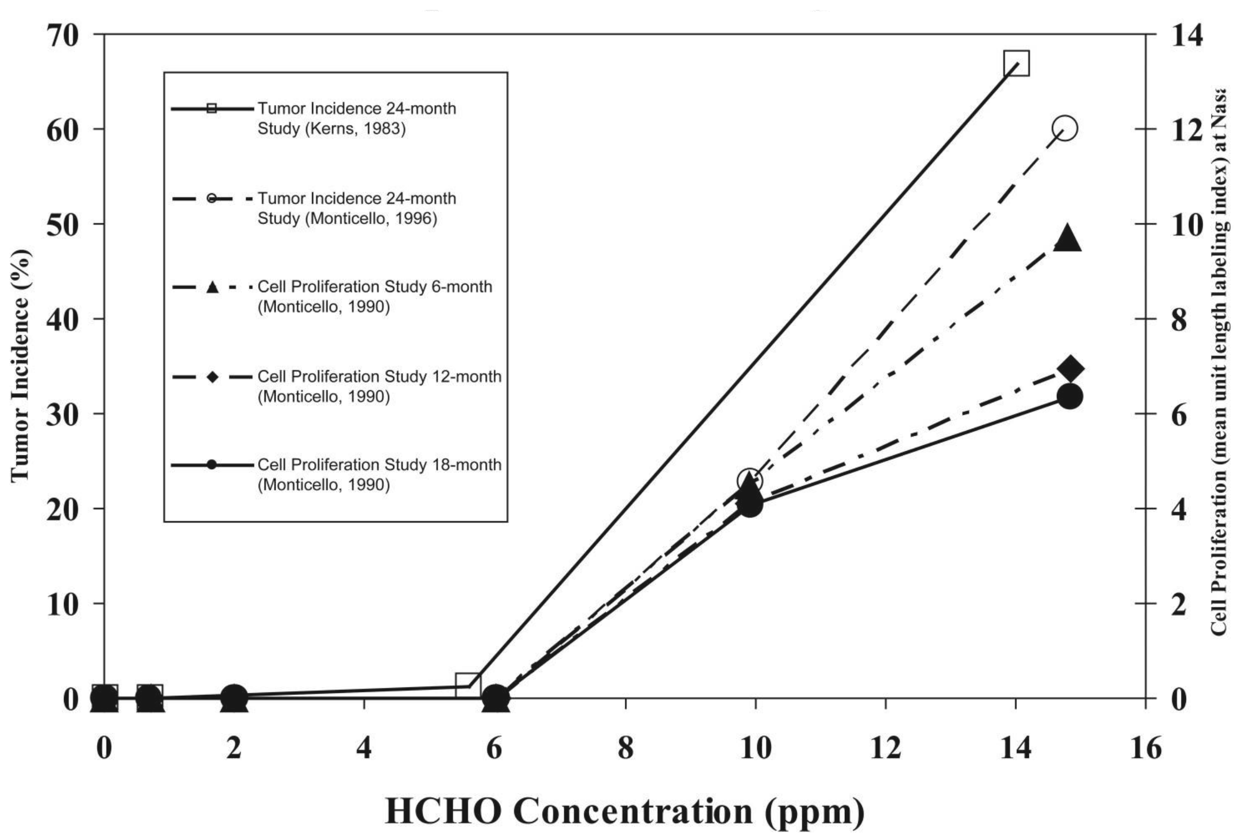
B-cell receptor signaling pathway[b]	0.008	0.003	0.004	
Insulin signaling pathway	0.015	0.035	0.052	
Adipocytokine signaling pathway	0.034	0.002	0.019	
Circadian rhythm—mammal	0.04	0.045	0.004	
RNA polymerase	< 0.001		0.048	
Toll-like receptor signaling pathway[b]	< 0.001	0.002	0.001	0.004
Epithelial cell signaling in *Helicobacter pylori* infection[b]	< 0.001	0.003	0.006	0.011
GPI-anchor biosynthesis[b]	< 0.001	0.041	< 0.001	0.007
T-cell receptor signaling pathway[b]	0.005	0.002	0.005	0.018
Apoptosis[b]	0.007	0.002	0.007	0.013
Cytokine–cytokine receptor interaction[b]	0.036	0.011	0.030	0.004
AML[b]	0.037	0.002		0.045
Fatty acid metabolism	0.037		0.049	0.033
Nucleotide excision repair	0.001		0.008	0.005
Renal cell carcinoma		0.024	0.015	
Protein export		0.053	0.024	
Steroid biosynthesis			0.004	0.034
Fc epsilon RI signaling pathway		0.006		0.046
Jak-STAT signaling pathway		0.003		0.048
MAPK signaling pathway		0.009		0.023

Note. Figure 1 is taken from the study *Global Gene Expression Profiling of a Population Exposed to a Range of Benzene Levels* conducted by McHale and collaborators.

Formaldehyde

To determine the carcinogenic effects of formaldehyde, Swenberg and contributors include an experiment performed by Monticello and Kerns. In this experiment, Monticello and Kerns exposed rats to formaldehyde after 6, 12, 18, and 24 months. The colleagues measured the amount of cell proliferation, demonstrating tumor growth (Swenberg *et al.,* 2012). As the concentration of formaldehyde increased, the percentage for tumor incidence increased, showing that an exposure to formaldehyde directly correlated to cancer growth. When exposed to 14 ppm of formaldehyde, each of the rats from the different studies ends up with anywhere from a 30% to a 70% higher tumor incidence rate than when not exposed to formaldehyde (Swenberg *et al.,* 2012). Although Monticello and Kerns exposed rats to formaldehyde, humans actually are more sensitive to formaldehyde's health risks. According to the USEPA, humans would face the same carcinogenic effects as rats at 0.46 the amount of exposure. Therefore, humans are around twice as sensitive to formaldehyde in comparison to rats (Swenberg *et al.,* 2012).

Figure 2: Tumor Incidence of Rats Exposed to Different Formaldehyde Concentrations (ppm)



Note. Figure 2 is taken from Swenburg and contributors in *Formaldehyde Carcinogenicity Research: 30 Years and Counting for Mode of Action, Epidemiology, and Cancer Risk Assessment*, and this figure displays the original data from Monticello and Kerns' experiment.

Arsenic

Chen and collaborators performed a study in Taiwan that measured the mortality risk of developing kidney, bladder, lung, and liver cancer in drinking water with various arsenic levels (Smith *et al.,* 1992). As more water was ingested, people developed a higher risk for cancer. Additionally, the highest mortality rates were found in people who have consumed around 800 µg/L. Moreover, the cancers that someone is most likely to contract from arsenic exposure are bladder cancer and kidney cancer. Overall, females are more susceptible to develop these cancers than men.

Figure 3: The Mortality Risk Ratio at Different Levels of Arsenic in Drinking Water Resulting from Different Cancer Types

Cancer site	Sex	Water levels, µg/L				*p*-Value for linear trend
		Background	170	470	800	
Liver	M	1.0	1.2	1.5	2.5	<0.001
	F	1.0	1.6	2.1	3.6	<0.001
Lung	M	1.0	1.8	3.3	4.5	<0.001
	F	1.0	2.8	4.3	8.8	<0.001
Bladder	M	1.0	5.1	12.1	28.7	<0.001
	F	1.0	11.9	25.1	65.4	<0.001
Kidney	M	1.0	4.9	11.9	19.6	<0.001
	F	1.0	4.0	13.9	37.0	<0.001

Note. This figure is taken from *Cancer Risks from Arsenic in Drinking Water* and is based on the original data set from Chen and researchers (Smith *et. al.,* 1992).

Lead

Gillis and colleagues exposed several subjects to lead levels of around 4.4 µg/L to 5.8 µg/L. The collaborators then analyzed the gene expressions that were altered due to lead exposure (Gillis *et al.,* 2012). As Figure 4 demonstrates, the two most prevalent pathways that lead alters are the regulation of cell death and the decrease of regulation in macromolecule metabolism. Furthermore, because the p-value is infinitesimal for each affected pathway, there is a strong correlation between lead exposure and adverse health effects.

Figure 4: Genetic Regulation of Important Pathways that are Essential for Life are Impacted by Lead

Annotation Cluster 1	Enrichment Score: 4.6			
Category	**Term**	**Count**	**P-value**	**FDR**
GOTERM_BP_FAT	GO:0010941 ~ regulation of cell death	84	2.05E-05	0.04
GOTERM_BP_FAT	GO:0042981 ~ regulation of apoptosis	83	2.21E-05	0.04
GOTERM_BP_FAT	GO:0043067 ~ regulation of programmed cell death	83	3.15E-05	0.06
Annotation Cluster 2	**Enrichment Score: 4.4**			
Category	**Term**	**Count**	**P-value**	**FDR**
GOTERM_BP_FAT	GO:0010629 ~ negative regulation of gene expression	59	1.24E-05	0.02
GOTERM_BP_FAT	GO:0016481 ~ negative regulation of transcription	55	1.33E-05	0.02
GOTERM_BP_FAT	GO:0010558 ~ negative regulation of macromolecule biosynthetic process	62	1.97E-05	0.04
GOTERM_BP_FAT	GO:0031327 ~ negative regulation of cellular biosynthetic process	63	2.22E-05	0.04
GOTERM_BP_FAT	GO:0009890 ~ negative regulation of biosynthetic process	64	2.23E-05	0.04
GOTERM_BP_FAT	GO:0045934 ~ negative regulation of nucleobase, nucleoside, nucleotide and nucleic acid metabolic process	57	7.26E-05	0.13
GOTERM_BP_FAT	GO:0051172 ~ negative regulation of nitrogen compound metabolic process	57	1.05E-04	0.19
GOTERM_BP_FAT	GO:0010605 ~ negative regulation of macromolecule metabolic process	71	6.31E-04	1.14
Annotation Cluster 3	**Enrichment Score: 4.0**			
Category	**Term**	**Count**	**P-value**	**FDR**
GOTERM_BP_FAT	GO:0043068 ~ positive regulation of programmed cell death	50	9.01E-05	0.16
GOTERM_BP_FAT	GO:0010942 ~ positive regulation of cell death	50	1.00E-04	0.18
GOTERM_BP_FAT	GO:0043065 ~ positive regulation of apoptosis	49	1.47E-04	0.27
Annotation Cluster 4	**Enrichment Score: 3.8**			
Category	**Term**	**Count**	**P-value**	**FDR**
GOTERM_BP_FAT	GO:0016481 ~ negative regulation of transcription	55	1.33E-05	0.02
GOTERM_BP_FAT	GO:0045892 ~ negative regulation of transcription, DNA-dependent	41	4.50E-04	0.81
GOTERM_BP_FAT	GO:0051253 ~ negative regulation of RNA metabolic process	41	6.25E-04	1.13

Note. Figure 4 is taken from *Analysis of lead toxicity in human cells.*

Discussion

Based on Figures 1, 2, 3, and 4, consumers of fracking water can develop numerous health complications because fracking introduces hazardous volatile organic compounds, metals, and microorganisms into drinking water. Collectively, most of the human body systems are negatively impacted due to exposure of the contaminants. Furthermore, fracking water induces the alteration of cell processes and genes, and both are imperative for a person's survival. Because these pollutants alter the body in damaging ways, the impurities can essentially lead to cancer and possibly death. Accordingly, people should unequivocally consume clean water, one of the most essential yet limited resources.

Benzene

As shown in Figure 1, almost all of the pathways were affected by benzene exposure. One system that is affected by benzene is the immune system, for the figure demonstrates that the T-cell receptor signaling pathway has been altered. T-cells are crucial to the immune system because these cells attack foreign invaders, or pathogens; thus, if the regulation of T-cells is not maintained properly, the immune system will not be able to function correctly. Another human body system that is negatively affected is the digestive system. According to Figure 1, the probability of developing an infection from *Heliobacter pylori* from all levels of benzene exposure is quite significant. An infection from *H. pylori* incites several complications to the digestive system, including the formation of stomach ulcers (Budzyński and Kłopocka, 2014). Benzene can also interfere with the synthesis of macromolecules, the main building blocks of life. For example, benzene exposure indicates a strong correlation with the alteration of RNA polymerase. RNA polymerase synthesizes RNA, a type of nucleic acid that makes up a person's genes. Additionally, benzene affects the formation of steroids, a type of lipid. Ultimately, the changes of the human body caused by benzene leads to cancer, such as leukemia, lung cancer, and pancreatic cancer. Therefore, benzene exposure from fracking water can lead to adverse health complications throughout the human body.

Formaldehyde

Figure 2 shows a strong relationship between formaldehyde exposure and the chances of developing a tumor. Tumors can spread to other tissues in the body, which can form even more tumors that can be lethal to the body. Moreover, the amount of cell proliferation increases due to formaldehyde exposure, allowing cancer cells to rapidly multiply and further disseminate throughout the body (National Cancer Institute, 2015). If citizens ingest fracking water that contains formaldehyde, there is a likely chance that these people will develop cancer.

Arsenic

According to Figure 3, exposure to arsenic displays a significant relation to developing liver, lung, kidney, and bladder cancer; without these essential organs, the human body cannot function properly. The liver is vital to the digestive system, lungs are crucial for the respiratory system, and the bladder and kidneys are important for the urinary system. Therefore, all of these body systems will be detrimentally impacted if a person consumes fracking water that contains any level of arsenic.

Lead

Figure 4 indicates a variety of essential pathways that are genetically altered by lead. Similar to benzene, lead impacts the regulation of processes revolving around macromolecules. The main macromolecule impacted by lead exposure is nucleic acids, or DNA and RNA. The alteration of nucleic acids is hazardous because nucleic acids code for every living organism; therefore, the disruption of genes can impact how the body functions. Furthermore, nucleic acids enable protein synthesis. Proteins execute a wide variety of functions, such as defense, transport, structure, and carry out chemical reactions. All of these important functions are obstructed by lead exposure, for lead causes a down regulation of protein synthesis. Lead also promotes cell apoptosis, which can be malignant if the amount of cell death is not regulated properly. As a result of living near fracking locations, where the drinking water will contain toxic heavy metals such as lead, people will develop dangerous cancers and other issues.

Microorganisms

Although microorganisms are not the main source of cancer induction from fracking water, microorganisms still contribute to other health concerns. Microorganisms mainly cause complications in the digestive system, for these microbes can lead to inflammatory bowel disease and chronic constipation. Furthermore, microorganisms cause obesity in patients. According to the CDC, obesity can lead to a higher risk for heart disease, diabetes, cancer, and mental disorders (CDC, 2020). Thus, microorganisms do not directly lead to cancer, but these microbes can cause other health implications that increase the risk for cancer and other malignancies.

Limitations

Though this paper mainly focuses on the effect of volatile organic compounds, metals, and microorganisms on human health, there are other contaminants in fracking water. Among these other contaminants are inorganic compounds and inorganic compounds. Certain inorganic compounds, such as nitrates and nitrites can be detrimental to health, for these contaminants can lead to blue baby syndrome (EWG, 1996). Furthermore, radioactive elements can disrupt the genetic code, potentially leading to cardiovascular disease and cancer (EPA, 2019). However, for the purpose of this paper, the health effects of volatile organic compounds, metals, and microorganisms displayed an overall perspective of the health complications from fracking water.

Suggestions for Future Research

Because fracking water leads to adverse health implications, discovering an effective method for purifying water is essential for the population. Although disbanding fracking companies may seem like a more impactful alternative, fracking provides economic benefit to these companies; as such, assuming that an individual can easily stop fracking companies would be impractical. Thus, the most economically friendly and efficient strategy is to research effective filtration methods to convert fracking water into a drinkable source of water.

Conclusion

As the years progress, water has become an increasingly limited resource due to pollution. In order to raise awareness about the significance of clean water, this paper focuses on the hazardous health implications caused by contaminated water. One major source of water contamination is fracking, for many of the chemicals used for the process are disposed of into the water aquifer. The contaminants of interest in this paper are benzene, formaldehyde, arsenic, lead, and microorganisms, which are representative of the other pollutants found in fracking water. In addition, this paper presents how ingestion of these contaminants can lead to health issues such as cancer, diseases, human body system dysfunctions, and improper regulation of cell processes.

Since each contaminant in fracking water targets different systems of the body, this water will collectively be quite lethal to consume. Fracking water contains benzene, a volatile organic compound that leads to leukemia, pancreatic cancer, immune system dysfunction, mitochondrial damage, and high levels of oxidative stress. Another volatile organic compound in fracking water is formaldehyde, which induces respiratory tract illness, tumor growth, cell proliferation, and alterations to miRNA levels. In addition to volatile organic compounds, metals such as arsenic and lead are detected in fracking water. Not only does arsenic exposure cause lung, liver, kidney, and bladder cancer, but arsenic can also disrupt telomerase levels. Furthermore, lead-exposed patients can develop Parkinson’s disease, Alzheimer’s disease, neurological disorders, and oxidative stress. People can also develop obesity, inflammatory bowel disease, and chronic constipation due to the microorganisms in fracking water. Because fracking water can lead to all of these health complications, widespread access to clean water is imperative for improving public health. Without clean water, maintaining a healthy and safe life is nearly impossible.

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