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 natural gas fuels energy industries. The contaminants used in fracturing fluid pose a threat to human health. These contaminants can be categorized into volatile organic compounds, metals, inorganic compounds, dissolved solids, radioactive elements, and microorganisms. This paper presents a review of literature from studies exploring the adverse health effects of the following contaminants: benzene, formaldehyde, arsenic, lead, and microorganisms. By ingesting water near hydraulic fracturing sites, people can develop health complications including cancer, disease, body system dysfunction, and genetic disruption. Consequently, purifying contaminated water is necessary to sustain a healthy life.

Key Words: hydraulic fracturing, fracking, groundwater contamination, VOCs, heavy metals, bacteria, cancer

INTRODUCTION

Water is essential for all living organisms to survive, grow, and develop. Comprised of distinct chemical and physical properties, water is unique from other compounds. Water is the universal solvent and can form hydrogen bonds with compounds (Knight, Kalugin, Coker, & Ilgen, 2019). Humans depend on water to fulfill all cell processes, for it constitutes most of a person's blood. Blood is vital for cells, as red blood cells help move resources across the human body. Therefore, when someone is dehydrated, fewer nutrients are delivered to their cells, inhibiting cell growth and development. Since water comprises about two-thirds of the body, it is necessary for water to be clean. Otherwise, contaminants can disseminate through the bloodstream.

Unfortunately, water is polluted by hydraulic fracturing. Hydraulic fracturing, or fracking, is the process of injecting fluid at high pressure in underground rock formations to obtain methane, or natural gas. To increase pressure for rock disruption, fracking companies add contaminants to the fluid, including metals, volatile organic compounds (VOCs), and inorganic compounds (USEPA, 2020). Fracking wells have a chance of leaking, causing chemicals to disperse through the fractures and into the water aquifer (USEPA, 2017). The water aquifer is an underground source of water that can be used for drinking and irrigation; thus, people's drinking water can become contaminated from hydraulic fracturing. As a form of waste disposal, fracking fluid is further injected back into the ground, leading to further contamination (USEPA 2020).

This paper assesses the hazard of consuming contaminated water produced at fracking sites. The chemicals in fracking fluid are divided into groups: dissolved solids, VOCs, inorganic compounds, and metals. For the purpose of this review, the most lethal chemicals were chosen.

Of the VOCs, benzene was selected to represent the deleterious effects of aromatic hydrocarbons, and formaldehyde was chosen to represent aliphatic hydrocarbons' health effects. Arsenic and lead were designated to represent metals due to their carcinogenic properties. Although fracking fluid itself does not contain microorganisms, microorganisms inhabit fracking sites because they consume hydrocarbons in polluted water. Therefore, this paper also includes the harmful effects that microorganisms pose to human health. Because hydraulic fracturing introduces VOCs, metals, and microorganisms into water, consumers develop adverse health effects.

REVIEW OF LITERATURE

Benzene

One of the carcinogens in fracking water is benzene, an aromatic VOC that causes immune system dysfunction and acute myeloid leukemia. A study conducted by McHale and colleagues examined the injurious health effects associated with benzene exposure (McHale *et al.*, 2011). In this study, researchers sampled 250 shoe manufacturing workers who were exposed to benzene as well as 140 controls who were unexposed. Benzene was found to interfere with the immune system, specifically B-cell receptor signaling and T-cell receptor signaling. Moreover, researchers discovered that benzene altered ATP synthesis; this disruption is especially harmful since cells require ATP for energy to perform specialized cellular tasks. Benzene was also found to alter cell apoptosis, which can lead to several types of cancer such as acute myeloid leukemia.

The carcinogenicity of benzene is caused by metabolization, a process where molecules are broken down into energy that cells use to function (Smith 2010). After benzene is

metabolized, benzene's metabolites can disrupt the genetic code by causing chromosomal mutations. Although this single genetic disruption is not enough to cause leukemia, mutations from benzene's metabolites can accumulate over time. A study was conducted on mice that proved 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 genetic mutations, patients exposed to benzene's metabolites can develop cancer over time.

Although most research explores risk to high levels of benzene exposure, Carugno and collaborators demonstrated that benzene at low levels of exposure negatively impacts mitochondrial function (Carugno *et al.,* 2012). The mitochondria is vital for cells to obtain energy to execute cellular tasks. Without proper regulation of the mitochondria, energy production can be disrupted. To evaluate mitochondria, researchers examined blood mitochondrial DNA copy number, or mtDNAcn, which escalates whenever mitochondrial DNA has been damaged. Carugno and colleagues performed a study that proves low-level benzene exposure increase mtDNAcn. In Italy, the collaborators held a multicenter cross-sectional study on people exposed to low-levels of benzene through cigarette smoke 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 than in unexposed individuals. In Milan, individuals displayed an 8.2% increase of mtDNAcn when exposed to benzene. Based on the data, benzene caused the levels of mtDNAcn to increase, which showed the patients' mitochondrial DNA had been damaged. This increase of mtDNAcn was associated with a higher risk of developing lung cancer and non-Hodgkin lymphoma (Carugno *et al.,* 2012).

Increased blood mtDNAcn levels were also associated with cells that face oxidative stress (Carugno *et al*., 2012). Oxidation can occur in the human body due to reactive oxygen species (ROS). When cells are exposed to benzene, the amount of ROS increases above healthy levels. While ROS bolsters the immune system by blocking foreign invaders, an unregulated amount of ROS can lead to oxidative damage and premature cell apoptosis. Mitochondrial DNA (mtDNA) are especially prone to ROS damage because they have less protective histones. When cells are impacted with ROS, more copies of mtDNA are created to compensate for damage. While this seems like a beneficial mechanism, increased mitochondria generates more ROS, inducing further oxidative damage and cell death (Carugno *et al*., 2012).

Formaldehyde

Hydraulic fracturing water also includes formaldehyde, an aliphatic hydrocarbon and known carcinogen. According to the National Cancer Institute cohort, including over 25,000 formaldehyde-exposed workers in 10 plants, formaldehyde exposure was associated with increased nasopharyngeal cancer (Swenberg *et al.*, 2012). In addition, formaldehyde increased the risk of adult and childhood asthma and acute respiratory tract illness. Because formaldehyde is highly reactive in air and is water soluble, 95% of formaldehyde can be inhaled and absorbed within the nasal and upper airways. Furthermore, formaldehyde altered pathways associated with inflammatory response, cancer, and endocrine system regulation (Rager *et al.,* 2011).

Exposure to formaldehyde can also reconfigure the genetic code in nasal and lung cells by altering amounts of microRNA, or miRNA. miRNA induces cellular disease and regulates gene expression after transcription (Rager *et al.,* 2011). Alteration of miRNA levels cause

cardiovascular diseases, cancer, diabetes, and obesity. On a smaller scale, this can impact the degree of cell apoptosis, cell proliferation stress response, and metabolism (Adlakha & Saini, 2014). To verify that formaldehyde modified miRNA levels, 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 tumors and chromosome loss, ultimately causing cancer, including breast cancer and leukemia (Rager *et al.*, 2011).

Arsenic

Along with VOCs, fracking water contains metals, and one prevalent metal in fracking water is arsenic. Arsenic is typically found in an inorganic form in drinking water, yet arsenic's colorless, tasteless, and odorless state makes it difficult to detect (Naujokas *et al.,* 2013). In general, United States wells contained over 3000 µg/L of arsenic. As indicated by the United States Environmental Protection Agency (USEPA), the maximum safety level for arsenic is 10 µg/L (Naujokas *et al.,* 2013). Furthermore, 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. Arsenic was found to cause several types of cancer, including lung, liver, kidney, bladder, and skin cancer. Arsenic also induced negative immunological, neurological, cardiovascular, respiratory, and dermatological effects. Although these were the most common symptoms, some people developed skin lesions as well. Arsenic can also lead to deleterious health effects on the cellular level. For example, arsenic affected cellular proliferation, cellular signaling, apoptosis, and DNA structure (Naujokas *et al.,* 2013).

Arsenic also altered the genetic code by causing DNA damage, chromosome abnormalities, and oxidative stress (Mo *et al.,* 2009).

Arsenic also induces genetic instability throughout the body by disrupting telomerase activity (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, leading to cell apoptosis. Telomerase is an enzyme that attaches telomeric sequences to the chromosomes' ends when the cell divides to prevent chromosome degradation. Most normal cells have minimal or no detectable levels of telomerase activity, but tumor cells express larger levels of telomerase activity. Human telomerase consists of an enzymatic subunit called human telomerase reverse transcriptase (hTERT). In order to find the relation between arsenic and telomerase levels, Mo and researchers measured the hTERT mRNA levels in blood samples collected from residents of Inner Mongolia who had been exposed to arsenic in their drinking water. The researchers found that the mRNA levels of hTERT increased significantly at 0-1 μM of arsenic exposure. However, the mRNA levels of hTERT decreased at 2.5-10 μM of arsenic exposure. Both an increase and decrease of hTERT levels (telomerase activity) were injurious to human health. Decreased telomerase activity inhibited DNA repair and caused fragmented chromosomes. However, elevated levels of telomerase activity allowed cancer cells to overcome mortality, as these cells did not experience a loss of telomere length (and chromosome degradation) during cell proliferation (Mo et al., 2009).

Lead

Another injurious metal found in fracking water is lead, severely affecting both adults and children (Sanders *et. al.*, 2010). Lead impacts several parts of the brain: the prefrontal cerebral cortex, cerebellum, and hippocampus. When these pathways are targeted, people can develop neurological disorders such as Parkinson's disease, Alzheimer's disease, and schizophrenia. Lead ingestion also results in convulsions, comas, and decreased muscle coordination. Physically, lead exposure can cause muscle and joint pain in adults. Children are also impaired by lead, as children exposed to lead score lower on intelligence tests and exhibit lower hand-eye coordination and reaction time. For every exposure to 10 μg of lead, a child lost 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 (Sanders *et al.,* 2009).

Lead exposure can also disrupt biological functions at the cellular and molecular level by initiating cell apoptosis and altering mitochondrial function (Sanders *et al.,* 2009). Additionally, lead contact degraded an individual's genes in the brain, liver, and lung. Similar to benzene, lead generated ROS, which was dangerous to a person's health. ROS increase was directly correlated with neurological damage, as neurons lost the ability to remove ROS toxicity with oversaturated ROS levels. Lead also decreased antioxidants, and thereby, heightened oxidative stress (Sanders *et al.,* 2009).

Microorganisms

In addition to VOCs and metals, fracking water contains a diverse population of microorganisms. According to Kahrilas and colleagues, several microorganisms in fracking water were *Spirochetes, Clostridia, Synergistetes, Bacteroidetes* and proteobacteria. Furthermore,

sulfate-reducing bacteria resided in water near fracturing sites, which produced hydrogen sulfide. Because hydrogen sulfide gas caused corrosion of underground tubing, petroleum and other contaminants were leaked into the groundwater (Kahrilas *et al.,* 2015). Additionally, fracking water contained methanogens, microorganisms that produce methane. Some methanogens include *Archaea, Halomas,* and *Marinobacter* (Mouser *et al.,* 2016). Methanogens *Halomas* and *Marinobacter* inhabited fracking sites because these sites contained the aliphatic and aromatic hydrocarbons that enabled methanogens to thrive.

Although not all microorganisms are toxic, methanogens can induce adverse health implications. For instance, due to methanogens' ability to efficiently break down calories, drinking water containing methanogens caused humans to develop obesity since they required increased caloric intake (Chaudhary *et al.,* 2018). Furthermore, methanogens increased the production of fatty acids. Methanogens also heightened inflammatory bowel disease and chronic constipation (Lurie-Weinberger & Gophna, 2015).

RESULTS

Benzene

The study conducted by McHale and researchers underscored that benzene interfered with numerous pathways (McHale *et al.,* 2011). McHale and collaborators assessed the probability of the null hypothesis that benzene does not significantly interfere with various pathways. As shown by Figure 1, $p < 0.05$ for 67 cases, rejecting the null hypothesis. There were only two exceptions – at low levels of benzene for protein export ($p = 0.053$) and at high levels of benzene for insulin signaling pathway ($p = 0.052$).

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

Pathway name[a]	Benzene exposure category			
	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	
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

[a]KEGG pathways that are significant at ≥ 2 doses. [b]FDR-adjusted *p*-value (Benjamini and Hochberg 1995) < 0.005 in overall analysis. Details of all KEGG pathways are available from Kyoto Encyclopedia of Genes and Genomes (2000).

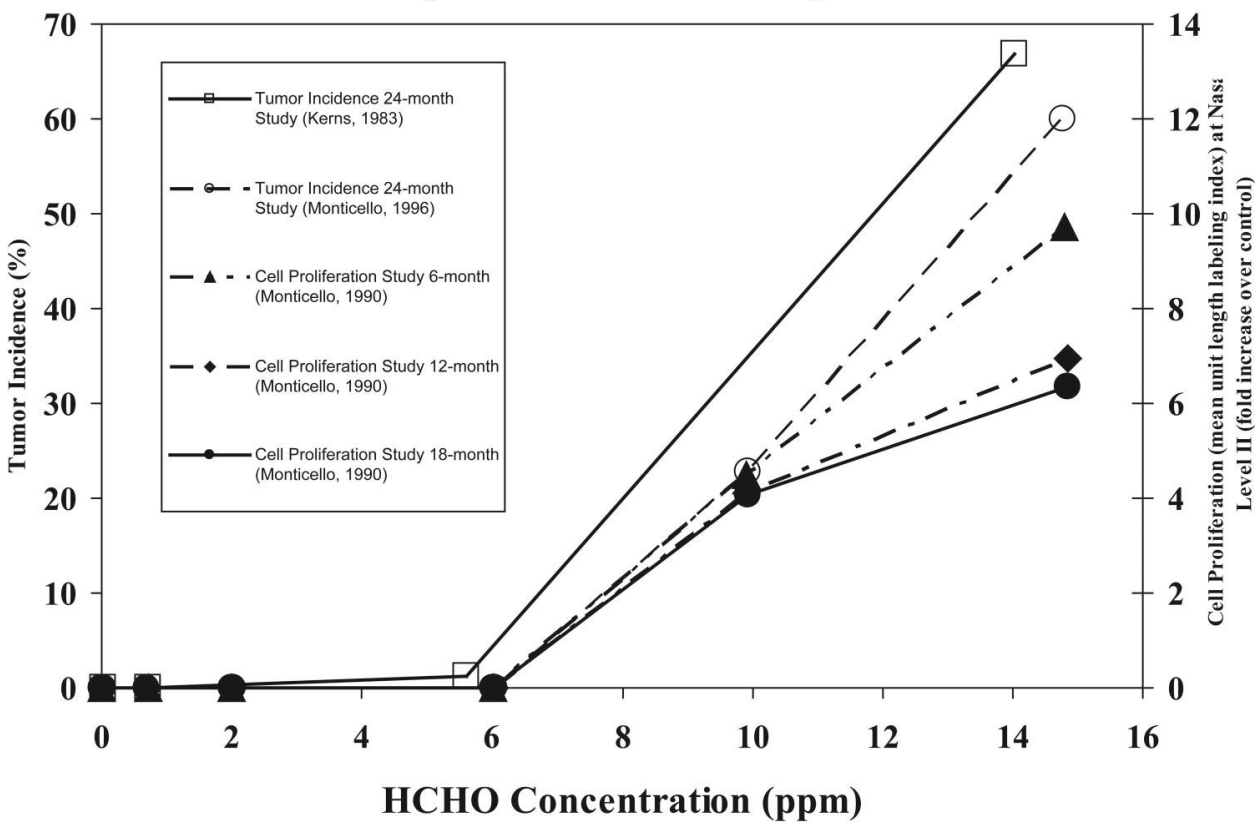
Note. Figure 1 was taken from the study *Global Gene Expression Profiling of a Population Exposed to a Range of Benzene Levels* conducted by McHale and collaborators.

Formaldehyde

To determine the carcinogenic effects of formaldehyde, an experiment performed by Monticello and Kerns was assessed (Swenberg *et al.,* 2012). In this experiment, Monticello and Kerns exposed rats to formaldehyde for 6, 12, 18, and 24 months. The colleagues measured the

amount of cell proliferation, demonstrating tumor growth. As shown in Figure 2, formaldehyde exposure was directly correlated to cancer growth. When exposed to 14 ppm of formaldehyde, the tumor incidence rate increased by 30-70% for each of the rats (Swenberg *et al.,* 2012). Although Monticello and Kerns exposed rats to formaldehyde, humans were around 2.17 times more sensitive than rats to formaldehyde (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 displayed 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 with various arsenic levels in drinking water (Smith *et al.,* 1992). As more water was ingested, people developed a higher risk for cancer. The highest mortality rates were found in people who have consumed around 800 µg/L. Specifically, the most frequent cancer contracted are bladder and kidney cancer. Overall, females were 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 was taken from *Cancer Risks from Arsenic in Drinking Water* and was based on the original data set from Chen and researchers (Smith *et. al.,* 1992).

Lead

Gillis and colleagues exposed subjects to ~4.4-5.8 µg/L lead and analyzed the gene expression (Gillis *et al.,* 2012). According to Figure 4, the two most prevalent pathways lead regulated were cell death and macromolecule metabolism. Furthermore, since $p < 0.05$ for each affected pathway, there was 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 was taken from *Analysis of lead toxicity in human cells.*

DISCUSSION

Based on Figures 1, 2, 3, and 4, consumers of fracking water developed numerous health complications because hydraulic fracturing introduced hazardous VOCs, metals, and microorganisms into drinking water. Collectively, most human body systems were negatively impacted due to contaminant exposure. Furthermore, fracking water altered cell processes and genes, leading 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 the pathways were affected by benzene exposure. One system affected by benzene was the immune system, specifically the T-cell receptor signaling pathway. T-cells are crucial for attacking pathogens; if the regulation of T-cells is not maintained properly, the immune system will not be able to function adequately. The digestive system was also impacted, as the probability of developing an infection from *Heliobacter pylori* from all levels of benzene exposure was significant. An infection from *H. pylori* led to stomach ulcer formation (Budzyński and Kłopocka, 2014). Benzene also interfered with RNA polymerase regulation, which is essential for RNA synthesis. Ultimately, these mutations caused by benzene can lead to cancer, such as leukemia, lung cancer, and pancreatic cancer.

Formaldehyde

Figure 2 revealed a strong relationship between formaldehyde exposure and the chances of tumor incidence. Cell proliferation increased due to formaldehyde exposure, allowing cancer

cells to rapidly multiply and further disseminate throughout the body (National Cancer Institute, 2015).

Arsenic

According to Figure 3, arsenic exposure was correlated with developing liver, lung, kidney, and bladder cancer. 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. Consequently, all of these body systems will be detrimentally impacted if a person consumes fracking water with any level of arsenic.

Lead

Figure 4 indicated a variety of pathways genetically altered by lead. Lead primarily dysregulated nucleic acids, which is hazardous because nucleic acids code for every living organism. Furthermore, nucleic acids enable protein synthesis; proteins execute a variety of functions such as defense, transport, structure, and catalysis. All of these important functions were obstructed by lead exposure, for lead caused a down regulation of protein synthesis. Lead also promoted cell apoptosis, which has a potential to be malignant.

Microorganisms

Microorganisms mainly caused complications in the digestive system, leading to inflammatory bowel disease and chronic constipation. Furthermore, microorganisms were correlated with increased obesity in patients. Obesity can lead to a higher risk for heart disease,

diabetes, cancer, and mental disorders (CDC, 2020). While microorganisms did not directly lead to cancer, they can cause other health implications that increase the risk for cancer and other malignancies.

Limitations

Though this paper mainly focused on the effect of VOCs, metals, and microorganisms on human health, there are other contaminants in fracking water. Among these other contaminants are inorganic compounds and radioactive elements. Certain inorganic compounds, such as nitrates and nitrites 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 scope of this paper, the health effects of VOCs, metals, and microorganisms represented a sufficient perspective of health complications.

Suggestions for Future Research

Because fracking water impairs human health, discovering an effective method for purifying water is essential. Although disbanding fracking companies may seem like a more impactful alternative, fracking provides economic benefit to these companies; as such, this approach may 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

Over time, water has become an increasingly limited resource due to pollution. 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 chemicals used in the process are disposed into the water aquifer. The contaminants of interest in this paper are benzene, formaldehyde, arsenic, lead, and microorganisms. In addition, this paper presents how ingestion of these contaminants cause health issues such as cancer, diseases, human body dysfunction, and improper regulation of cell processes.

Since each contaminant in fracking water targeted different body systems, fracking water is lethal to consume. Fracking water contains benzene, a VOC that leads to leukemia, lung cancer, immune system dysfunction, mitochondrial damage, and oxidative stress. Another VOC is formaldehyde, which induces respiratory tract illness, cell proliferation, and alterations to miRNA levels. In addition to VOCs, metals such as arsenic and lead were detected in fracking water. Arsenic exposure induces lung, liver, kidney, and bladder cancer and disrupts 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 microorganisms. Water contaminated by hydraulic fracturing is life-threatening, and widespread access to clean water is imperative for improving public health.

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