ASSESSMENT OF METHODS OF FLUORIDATION TO CONCLUDE MOST BENEFICIAL FOR HUMAN HEALTH AND THE ENVIRONMENT

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By

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I certify that I have read this thesis and that, in my opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in

Global Environmental Science.

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For my parents, Gabriel Henao and Miriam Ortega, who have given me endless support throughout the completion of this thesis and sacrificed everything in order for me to have a successful education.

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ABSTRACT

This thesis aims to critically assess the relative efficacy of various methods to provide fluoride treatment with respect to both reduction of tooth decay and environmental impact. Each method was scored against a number of criteria that fell under the three pillars of sustainability: Economic, Social, and Environmental. Each criteria was scored between 0 and 5, with 0 being the least and 5 being the highest. The results were plotted in the form of radar plots and the relative sustainability of each method compared by analyzing coverage. Results suggest that the municipal water method of fluoridation was the most sustainable and the bottled water method of fluoridation was the least sustainable. The combination of brushing regularly with toothpaste 1-3 times a day and using fluoride treatments as needed by dental professionals, along with drinking regularly from municipal water is the safest way to receive the oral benefits of fluoridation as well as protecting human health and the environment. These outcomes can be used to guide future public policy debate on fluoridation at the city, State and Federal level.

Estefania Henao, February 9th, 2022, University of Hawaii at Manoa

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1.0 INTRODUCTION

1.1 LITERATURE REVIEW

This thesis has used primary and secondary sources such as studies and journal articles to gain vital current information regarding fluoride toxicity and methods of application in order to assess the most appropriate pathway to fluoridate teeth that both protects the environment, human health, and provides effective protection against tooth decay. The primary sources used consisted of the Centers for Disease Control (CDC) and Environmental Protection Agency (EPA), which are both reliable federal agencies that are responsible for protecting the overall health of communities. Another source used was the American Dental Association (ADA) which is the largest and oldest association that ensures outstanding oral health for Americans by setting gold standards that ensure the safety and efficacy of dental protection and procedures. These primary sources were used to gain a better understanding and knowledge of current policies and recommendations on fluoride use throughout communities. Also, secondary sources such as peer reviewed scientific journals and articles written by accredited scientists and professionals who have outstanding knowledge and credentials on topics ranging from fluoride toxicity, forms of application, public health regulations, and potential controversies using fluoride for human health. These sources were mainly used to synthesize background information with individual data from specific studies and get a more in depth understanding on potential health and environmental concerns.

1.2 ORAL HEALTH BACKGROUND

Oral health is referred to as the health of a person's teeth, gums, and mouth (CDC, 2021). It is a universal key indicator of a person's overall health and quality of life due to the fact that it allows people to properly eat, talk, smile, and have proper social interactions. There are many ways over the years that humans have started to take better care of their oral health. These include regular brushing, flossing, reducing sugar consumption, early treatment of cavities by dentists, orthodontia, and fluoride treatment (ADA, 2021). Dental tooth fluoridation is the use of fluoride in order to improve the quality of a person's teeth by strengthening the enamel and protecting teeth from decay (ADA, 2021). When a person eats sugary foods there are bacteria in the mouth such as Streptococcus *mutans*, that produce acids. The acids decay a person's teeth by breaking down the enamel which causes tooth weakness, gingivitis, which increases the risk of cavities, also referred to as caries. Incorporation of fluoride onto the surface of the enamel increases resistance to enamel breakdown.

Dental health practices have improved substantially over time, one of the main ways is dental tooth fluoridation. Regarding tooth fluoridation, there are some controversies that challenge the integrity and impacts of using fluoride to improve humans oral health. Fluoride is applied in many different ways in order to achieve maximum benefits, there are two main methods of tooth fluoridation: topical and systemic.

In the early 1800's the majority of the population did not have accurate and affordable dental care, in turn, many people suffered from oral health diseases such as dental caries, tooth loss, and oral cancers. As a desperate solution, people would simply get their teeth pulled as it was the cheapest and fastest solution. In the mid 1800's dental practices and education became more apparent and essential. Organizations like the American Dental Association (ADA) were created and dental health became more important to the general public. In 1901, a doctor by the name of Frederick S. McKay, located in Colorado Springs, Colorado, discovered that a numerous number of his patients had a high prevalence of brown stains on their teeth (NIH, 2021). He investigated what potentially could be causing these brown stains in this specific community. McKay concluded that the cause of these stains was due to an agent in the public water supply, fluoride. He also concluded that the patients who had these stains were less susceptible to dental caries. This sparked interest and investigations regarding the relationship between fluoride and human teeth. In the beginning of the 20th century, dental caries became more common in the United States (NIH, 2021). This sparked an interest in finding a solution to counteract the increase in dental caries. Although there has been evidence that fluoride can reduce the incidence of dental caries there are controversies with its effects on human and the environment's health. Fluoride is applied in many different ways in order to achieve maximum benefits, there are two main methods of tooth fluoridation: topical and systemic.

1.2 METHODS OF FLUORIDATION

1.2.1. TOPICAL TOOTH FLUORIDATION

Topical tooth fluoridation is when fluoride is applied directly to the teeth (ADA, 2021). This is done by two main methods: self-applied and professionally-applied. Self-applied fluoride includes mouth rinses and toothpastes. Professionally-applied are fluoride therapies that are applied by a professional dentist which include higher-strength rinses, gels, foams, and fluoride varnishes.

Most toothpastes and mouth rinses have fluoride in them in order to strengthen the enamel and prevent cavities from occurring. Toothpaste and mouth rinses are among the most common ways people come into contact with fluoride with self-application. These two products are in most people's everyday routines even though they may not be fully aware they are using a product with fluoride. Since toothpaste and mouthwash are self bought and self-applied products it is important to inform the consumer what exact discrepancies are in the products they are using. Another form of topical tooth fluoridation is professionally applied fluoride, which occurs during general dentist appointments and cleaning. When fluoride is professionally applied by a dentist the types of fluoride products they use are higher-strength rinses such as gels, foams, and fluoride varnishes, which contain higher levels of fluoride. Higher-strength rinses, gels and foams, and fluoride varnishes aren't meant to be ingested, they at times can be accidentally.

1.2.2 SYSTEMIC TOOTH FLUORIDATION

Systemic tooth fluoridation is when fluoride is directly ingested in order to improve the conditions of a person's teeth. The main method of systemic tooth fluoridation is the fluoridation of municipal water but also includes bottled water/beverages, and fluoride supplements (ADA, 2021).

The main method of systemic tooth fluoridation is the Fluoridation of Municipal Water. This method is the most ethically challenged method of fluoridation for human health and environmental purposes. Since municipal water is fluoridated at the source, it raises a lot of questions as to whether people are aware of and consenting to fluoride in their water. The U.S. Department of Health and Services recommends an amount of 0.7 mg/L of Fluorosilicic Acid, a water based solution, to be added to community water systems (CDC, 2018). The fluoride is added at water treatment plants and is then distributed to homes all around the area. In 1945, the first city to fluoridate their water was Grand Rapids, Michigan (NIH 2021). As of 2018, approximately 73% of the United States population receives fluoridated water from their community water supply (CDC, 2018). Not every location of each state fluoridates their water, some cities and countries decide individually to not fluoridate their water. The District of Columbia has 100% of their population receiving fluoridated water which makes them the top city to get their whole population fluoridated. Hawaii on the other hand only has approximately 8.8% of their popula-

tion exposed to fluoridated water which classifies them as the state least exposing their public community to fluoridated water. The states that have the majority of the population drinking fluoridated water have a substantial decrease in tooth caries (~25%), especially in young children aged 0-6 years old (CDC, 2018). The portion of the population exposed to fluoridated water has slightly increased from the year 2000 where only 65.05% of the U.S. population received fluoridated water (CDC, 2018).

Another method of systemic water fluoridation is the ingestion of bottled water and fluoride supplements. Bottled water has become increasingly popular over the previous decade due to convenience since they are portable for people on the go. Most bottled water comes from freshwater sources which contain approximately 0.05 ppm of fluoride. Although, the average level of fluoride in bottled water is approximately 0.11 ppm (Connett, 2012). It has been confirmed that bottled water and fluoride have no relationship affecting one another signifying that fluoridated bottled water is ineffective in preventing tooth decay in people. Fluoride supplements are available in the USA by prescription only by a licensed physician. They are generally prescribed for children who aren't getting enough fluoride in their everyday life and diet. These supplements don't work for adults since their teeth are already formed and can actually cause negative effects such as fluorosis.

Before being able to analyze which fluoridation method is the most sustainable for human health and the environment, we must understand that fluoride is consumed

naturally through a person's diet, often unknowingly. Different types of food and drinks have various levels of natural fluoride content. Most of the population is not aware that they could be receiving a sufficient amount of fluoride simply through their diets. It is important to be cautious of negative impacts fluoride overconsumption especially when also using other methods of fluoridation on top of unknowingly getting it from a persons daily diet. Depending a persons diet, they made not even need to use any of the methods of fluoridation at all.

2.0 METHODS

2.1 ASSESSING FLUORIDE EFFICACY

In order to assess the overall sustainability of each method, fluoride efficacy for the 8 predominant methods of fluoridation was assessed. The first step in data collection and analysis consisted of compiling a list of 8 of the most common dental tooth fluoridation methods which consisted of: toothpaste, mouth rinse/mouthwash, foams, gels, varnishes, municipal water, and bottled water. Next, the table was divided into subcategories for each method which consisted of age group targeted, topical or systemic application, consistency of usage, concentration of fluoride, and metrics of importance to the dental community. After, the chart was filled out using data collected from primary sources and studies, the information was used to rank each method in order from 1 to 8 in terms of efficacy and importance to the dental community.

2.2 PATHWAYS OF FLUORIDE RELEASE TO ENVIRONMENT

Data collection and analysis consisted of reviewing and assessing the pathway of fluoride to the environment for each of the 8 methods listed in Table 1 (page 21). This data was collected to assess the overall sustainability of the methods regarding the environment. For each of the 8 methods subcategories were created that consisted of what form of fluoride is used, the beginning of the life cycle, the usage portion of the life cycle, the end of the life cycle, and how much of the fluoride component ends up in the en-

vironment. Using data collected from primary sources, the table gives information on environmental impacts that could occur due to fluoride exposure.

2.3 SUSTAINABILITY ASSESSMENT OF EACH PATHWAY

In order to assess the overall sustainability of each method of dental fluoridation scores were given under the three pillars of sustainability. For this portion of the data collection and analysis, nine impact categories were selected under the three pillars of sustainability. The three pillars of sustainability consist of environmental, economic, and social components which ensure the preservation of the planet and quality of life (EPA, 2011). For my analysis on the 8 methods of fluoridation, the following nine impact categories were selected: availability of use, likelihood of use, health benefits, health risks, manufacture costs, water consumption for production, energy usage for production, harmful impact on the environment, and fluoride discharge rate to the environment. Using the data collected from tables 1 and 2, background information, and previous data collected, each of the nine impact categories were scored on a scale of 0-5, 0 being unsustainable and 5 being extremely sustainable. In order to score each impact category accurately on a scale of 0-5 for sustainability, primary references will be used to ensure accurate data. In conclusion, the data will conclude the relative sustainability for each of the eight methods of dental tooth fluoridation regarding each of the nine impact categories.

2.4 PLOTTING DATA USING RADAR PLOTS

Radar plots were used to present and compare the nine scores for each pathway of dental tooth fluoridation. Radar plots give a visual comparison for each of the methods for the 3 pillars of sustainability and the scores for each of the nine impact categories . The nine impact categories are divided into 3 subsections: Economic, Environmental, and Social. The computer program used to create the radar plots was Microsoft Excel. The relative shapes for each plot are going to be used for a basis of comparison.

2.5 RADAR PLOT ANALYSIS

The overall sustainability of each pathway was evaluated by using the general shape of each plot along with anecdotal judgment. The radar plots allow for a visual comparison of the different pathways depending on their scores for each of the nine impact categories for each of the subsections of the pillars of sustainability: Economic, Social, and Environmental. Analyzing the shapes of the 8 radar plots will create concise conclusions about how each of the methods of fluoridation impact overall sustainability.

3.0 RESULTS

3.1 Data Collection

The first portion of the results is the Data Collection. In this section, primary and secondary sources were used to gather information regarding the sustainability of the 3 impact categories selected for this analysis. Table 1 is identifying the pathway of fluoride to the environment and whether each of the 8 methods causes environmental damage. Tables 2, 3, and 4 were used to confirm the values from 0, unsustainable to 5, sustainable for the three impact categories. Table 5 gathered all the data into one table and ranked the methods from most to least sustainable by multiplying the nine impact category scores together to get an overall score. The data collected from these Tables will allow a visual display of the information gathered for analysis and conclusions.

3.1.1 Pathway of Fluoride Exposure to the Environment

Table 1. This table reviews and assesses the pathway of fluoride to the environment from cradle to grave for all 8 considered methods of tooth fluoridation. The variables on the table consist of the type of fluoride used, beginning of life cycle, usage portion of life cycle, end of cycle, and with all those variables we determine how much of the fluoride ends up in the environment.

Methods of Fluoridation	**What form of fluoride?**	**Cradle side of Life Cycle**	**Usage Portion of Life Cycle**	**End of Life Cycle**	**Environmental Damage**
Mouthwash	Sodium fluoride	Fluoride applied in manufacturing	Consumer Usage- -38.1% never used mouthwash -17.5% used mouthwash less than once a month -19.4% used mouthwash once every few days -25.1% used mouthwash daily	Sewage system that drains into the ocean	Other products in mouthwash such as sodium lauryl sulfate, polysorbate, cetylpyridinium chloride and benzalkonium chloride that are also in mouthwash are toxic to organisms in aquatic environments. Also, containers produce plastic waste. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3886070/
Toothpaste	Sodium fluoride and stannous fluoride	Fluoride applied in manufacturing	Daily (2-3 times a day)	Sewage system that drains into the ocean	Plastic Waste
Gels	Acidulated phosphate fluoride*	Fluoride applied in manufacturing	Professionally applied (x2 a year)	Sewage system that drains into the ocean	Plastic Waste
Varnishes	Sodium fluoride	Fluoride applied in manufacturing	Professionally applied (x2 a year)	Sewage system that drains into the ocean	Plastic Waste.
Foams	Acidulated phosphate fluoride and sodium fluoride	Fluoride applied in manufacturing	Professionally applied (x2 a year)	Sewage system that drains into the ocean	Plastic Waste
Municipal Water Fluoridation	Hexafluorophosphate	Fluoride applied in water treatment plants	From the tap	Consumed or ingested or sewage system that drains into the ocean	No effect. https://www.cdc.gov/fluoridation/pdf/pollick.pdf
Bottled Water	Sodium Fluoride	Fluoride applied in manufacturing	Purchased from the store	Consumed/ Ingested	Plastic Waste

Fluoride Supplements	Sodium Fluoride	Fluoride applied in manufacturing	Pharmacy-Prescribed by a doctor	Consumed/ Ingested	No effect. https://www.cdc.gov/fluoridation/pdf/pollick.pdf

*Acidulated phosphate fluoride consists of a mixture of sodium fluoride, hydrofluoric acid and orthophosphoric acid

3.1.2 Relative Sustainability of each Method of Tooth Fluoridation for the Environmental Pillar of Sustainability

Table 2. This table scores the relative sustainability for the Environmental pillar of sustainability for all 8 methods of tooth fluoridation. The environmental pillar of sustainability is broken into 3 impact categories: Impact on Environment, Toxicity, Plastic Pollution. These impact categories are then scored, on a scale of 0-5, 0 indicating unsustainability, 5 indicating high sustainability.

Pillar of Sustainability	**ENVIRONMENT PILLAR**		
Method of Fluoridation	**Impact on Environment**	**Toxicity**	**Plastic Pollution**

Mouthwash	2 Other products in mouthwash such as sodium lauryl sulfate, polysorbate, cetylpyridinium chloride and benzalkonium chloride that are also in mouthwash are toxic to organisms in aquatic environments. Table 1.	3 225-450 ppm https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	4 “Countless mouthwash bottles that won’t decay for decades or longer” https://massihortho.com/how-your-oral-hygiene-routine-may-be-hurting-the-environment/
Toothpaste	2 Plastic Pollution Table 1.	3 1000-1500ppm https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	4 “An estimated 400 million toothpaste tubes are discarded every year in the U.S., and at least 1.5 billion globally.” https://www.asyousow.org/blog/2019/12/9/colgate-recyclable-plastic-toothpaste-tube
Gels	2 Harmful to marine life after disposal Table 1.	1 12,300 ppm https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	2 https://ods.od.nih.gov/factsheets/Fluoride-HealthProfessional/#:~:text=According%20to%20the%20EPA%2C%20typical,mg%20for%20adults%20%5B10%5D.
Varnishes	2 Harmful to marine life after disposal. Table 1.	1 22,600ppm https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	2 https://ods.od.nih.gov/factsheets/Fluoride-HealthProfessional/#:~:text=According%20to%20the%20EPA%2C%20typical,mg%20for%20adults%20%5B10%5D.
Foams	2 Harmful in large to marine life after disposal. Table 1.	2 9,040ppm https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	2 https://ods.od.nih.gov/factsheets/Fluoride-HealthProfessional/#:~:text=According%20to%20the%20EPA%2C%20typical,mg%20for%20adults%20%5B10%5D.

3.1.3 Relative Sustainability of each Method of Tooth Fluoridation for the Economic Pillar of Sustainability

Table 3. This table scores the relative sustainability for the Economic pillar of sustainability for all 8 methods of tooth fluoridation. The economic pillar of sustainability is broken into 3 impact categories: Recyclable, Costs, Resource Consumption for Production. These impact categories are then scored, on a scale of 0-5, 0 indicating unsustainability, 5 indicating high sustainability.

Pillar of Sustainability	**ECONOMIC PILLAR**		
Method of Fluoridation	**Recyclable**	**Costs**	**Resource Consumption for Production**
Mouth wash	5 Plastic containers along with their rigid lids (shampoo, mouthwash, etc.) are recyclable. https://www.westerndisposal.com/recycling-in-the-bathroom/	4 5$ - 15$ https://www.heb.com/category/shop/health-beauty/oral-hygiene/mouthwash/490096/490423	1 Our single-use disposable ways require us to create a whole new item the next time we need that item. Creating new stuff every time we need it takes tremendous energy and natural resources. https://ecodentistry.org/green-dentistry/what-is-green-dentistry/reduce-waste/

Toothpaste	2 “ Toothpaste tubes are often made with a combination of different plastics and a thin layer of aluminum. This mix of materials makes them hard to recycle and it is unlikely they are accepted through your curbside recycling pickup.” https://earth911.com/health/recycling-toothbrushes-and-toothpaste-tubes/	5 4-7 https://www.statista.com/statistics/1061119/average-price-of-leading-us-toothpaste-brands/	1 “Our single-use disposable ways require us to create a whole new item the next time we need that item. Creating new stuff every time we need it takes tremendous energy and natural resources.” https://ecodentistry.org/green-dentistry/what-is-green-dentistry/reduce-waste/
Gels	2 Disposed of in trash, not recyclable due to excess product leftover in containers. *Primary Source	2 20 $-50 $ https://meadowdaledc.com/fluoride-treatment-cost/	1 Our single-use disposable ways require us to create a whole new item the next time we need that item. Creating new stuff every time we need it takes tremendous energy and natural resources. https://ecodentistry.org/green-dentistry/what-is-green-dentistry/reduce-waste/
Varnishes	2 Disposed of in trash, not recyclable due to excess product leftover in containers. (Dr. Henao)	2 20 $-50 $ https://meadowdaledc.com/fluoride-treatment-cost/	1 Our single-use disposable ways require us to create a whole new item the next time we need that item. Creating new stuff every time we need it takes tremendous energy and natural resources. https://ecodentistry.org/green-dentistry/what-is-green-dentistry/reduce-waste
Foams	2 Disposed of in trash, not recyclable due to excess product leftover in containers.	2 20 $-50 $ https://meadowdaledc.com/fluoride-treatment-cost/	1 Our single-use disposable ways require us to create a whole new item the next time we need that item. Creating new stuff every time we need it takes tremendous energy and natural resources. https://ecodentistry.org/green-dentistry/what-is-green-dentistry/reduce-waste/
Municipal Water Fluoridation	5 No waste https://www.cdc.gov/fluoridation/pdf/pollick.pdf	5 Free https://www.epa.gov/sites/default/files/2015-10/documents/2011_fluoride_questionsanswers.pdf	5 Directly Ingested “Fluoride can also be added to public drinking water supplies as a public health measure for reducing cavities among the treated population.” https://www.epa.gov/sites/default/files/2015-10/documents/2011_fluoride_questionsanswers.pdf
Bottled Water	4 Recyclable, but not always recycled.	4 1.50 $ https://www.drinkoptimum.com/the-true-cost-of-bottled-water/	2 “Other bottled water products (such as spring water) can contain fluoride that is added or naturally present in the original source of the water.” https://www.epa.gov/sites/default/files/2015-10/documents/2011_fluoride_questionsanswers.pdf

Fluoride Supplements	3 Ingested	2 15$ https://www.drugs.com/price-guide/fluoride	5 Directly Ingested

3.1.4 Relative Sustainability of each Method of Tooth Fluoridation for the Social Pillar of Sustainability

Table 4. This table scores the relative sustainability for the Social pillar of sustainability for all 8 methods of tooth fluoridation. The social pillar of sustainability is broken into 3 impact categories: Health Risks, Health Benefits, and Participation. These impact categories are then scored, on a scale of 0-5, 0 indicating unsustainability, 5 indicating high sustainability.

Pillar of Sustainability	**SOCIAL PILLAR**		
Method of Fluoridation	**Health Risks 5 = high risk**	**Health Benefits 5= high benefits**	**Participation**

Mouthwash	4 “Unfortunately, mouthwash doesn't differentiate and kills all bacteria. As a result, mouthwash can cause harm in the long run because it can disrupt the microbiome and impede the normal functioning of your body.” https://www.geisinger.org/health-and-wellness/wellness-articles/2018/01/29/20/46/is-mouthwash-safe-to-use-every-day	2 “The fluoride from mouthrinse is retained in dental plaque and saliva and helps prevent tooth decay.” https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	3 199.56 million people/year https://www.statista.com/statistics/276434/us-households-usage-of-mouthwash-and-dental-rinse/
Toothpaste	2 “Too much fluoride can pose risks to health, but the amounts contained in toothpaste are generally safe if a person uses the toothpaste as advised.” https://www.medicalnewstoday.com/articles/fluoride-toothpaste	5 “Fluoride toothpaste is very effective in preventing tooth decay.” https://www.dentalhealth.org/fluoride	5 307.17 million people/year https://www.statista.com/statistics/287376/usage-of-toothpaste-in-the-us-trend/
Gels	4 ”Because these applications are relatively infrequent, generally at 3- to 12-month intervals, fluoride gel poses little risk for dental fluorosis, even among patients younger than 6 years of age.” https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	4 “Routine use of professionally applied fluoride gel or foam likely provides benefit only to persons at high risk for tooth decay, especially those who do not consume fluoridated water and brush daily with fluoride toothpaste.” https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	2 Every 3, 6, or 12 months depending on oral health condition https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements
Varnishes	4 “According to the Centers for Disease Control and Prevention (CDC), there is no published evidence to indicate that professionally applied fluoride varnish is a risk factor for dental fluorosis, even among children younger than 6 years of age.” https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	4 “The U.S. Preventive Services Task Force recommends the clinical application of fluoride varnish to the primary teeth of all infants and children starting at the age of primary tooth eruption.” https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	2 Every 3, 6, or 12 months depending on oral health condition https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements

Foams	3 ”Because these applications are relatively infrequent, generally at 3- to 12-month intervals, fluoride gel poses little risk for dental fluorosis, even among patients younger than 6 years of age.” https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	4 Routine use of professionally applied fluoride gel or foam likely provides benefit only to persons at high risk for tooth decay, especially those who do not consume fluoridated water and brush daily with fluoride toothpaste. https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	2 Every 3, 6, or 12 months depending on oral health condition https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements
Municipal Water Fluoridation	3 “Chronic high-level exposure to fluoride can lead to skeletal fluorosis. In skeletal fluorosis, fluoride accumulates in the bone progressively over many years. “ https://www.who.int/teams/environment-climate-change-and-health/water-sanitation-and-health/burden-of-disease/other-diseases-and-risks/fluorosis	4 Studies show that water fluoridation continues to be effective in reducing tooth decay by 20% to 40% in children and adults, even in the era of widespread availability of fluoride from other sources, such as fluoride toothpaste. https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	5 207.4 million https://www.cdc.gov/fluoridation/statistics/2018stats.htm
Bottled Water	1 Minimal to no fluoride content in bottled water confirms low risk. https://www.cdc.gov/fluoridation/faqs/bottled_water.htm	3 “Bottled water may not have a sufficient amount of fluoride, which is important for preventing tooth decay and promoting oral health.” https://www.cdc.gov/fluoridation/faqs/bottled_water.htm	2 65.4 million https://www.statista.com/statistics/237832/volume-of-bottled-water-in-the-us/
Fluoride Supplements	2 For children aged younger than 6 years, health care providers should weigh the risk for tooth decay without fluoride supplements, the decay prevention offered by supplements, and the potential for dental fluorosis. https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	3 The U.S. Preventive Services Task Force recommends the clinical use of oral fluoride supplementation starting at age 6 months through 5 years for children whose water supply is deficient in fluoride. https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements	1 “All dietary fluoride supplements must be prescribed by a dentist or physician.” https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements

3.1.5 Sustainability Table

Table 5. Final scores for analysis by combining the scores from each of the nine impact categories, multiplying them together, and getting a final score. The higher the score the more sustainable the fluoridation method, the lower the score the less sustainable the method.

Methods of Fluoridation	Total Sustainability Score	Sustainability Rank (1-8)
Mouthwash	28	3
Toothpaste	29	2
Gels	20	6
Varnishes	19	8
Foams	20	7
Municipal Water	39	1
Bottled Water	25	5
Fluoride Supplements	27	4

3.2 RADAR PLOTS

The second portion of the data collection consisted of radar plots that conclude the sustainability for each of the methods of fluoridation, depending on their impact categories. For each of the plots, the 3 impact categories for each of the 3 pillars of sustainability are grouped together to show if there is favor to any of the pillars specifically. The impact categories are scored on a scale of 0, unsustainable to 5, sustainable depending on Data Collection (Tables 2, 3, & 4) and anecdotal data.

3.2.1 Mouthwash Radar Plot

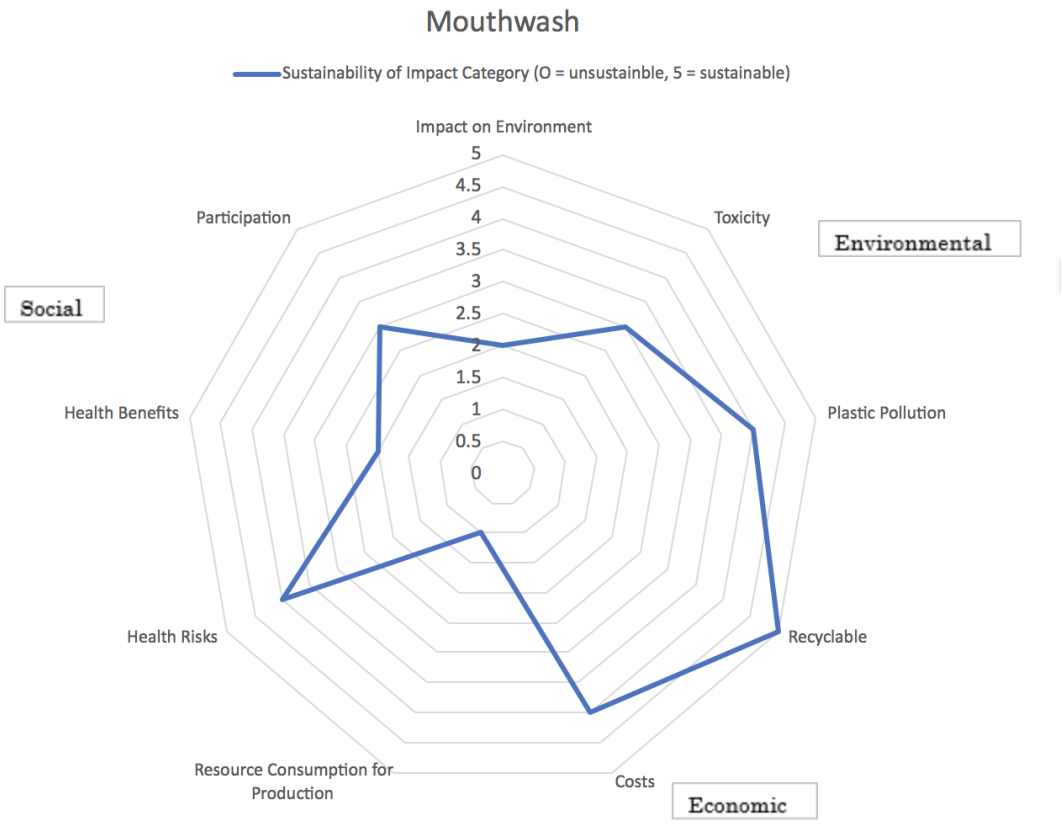

Figure 1. Mouthwash radar plot is demonstrating various levels of sustainability for each of nine impact categories under the pillars of sustainability. It is on a score of 0 meaning unsustainable and 5 meaning sustainable.

3.2.2 Toothpaste Radar Plot

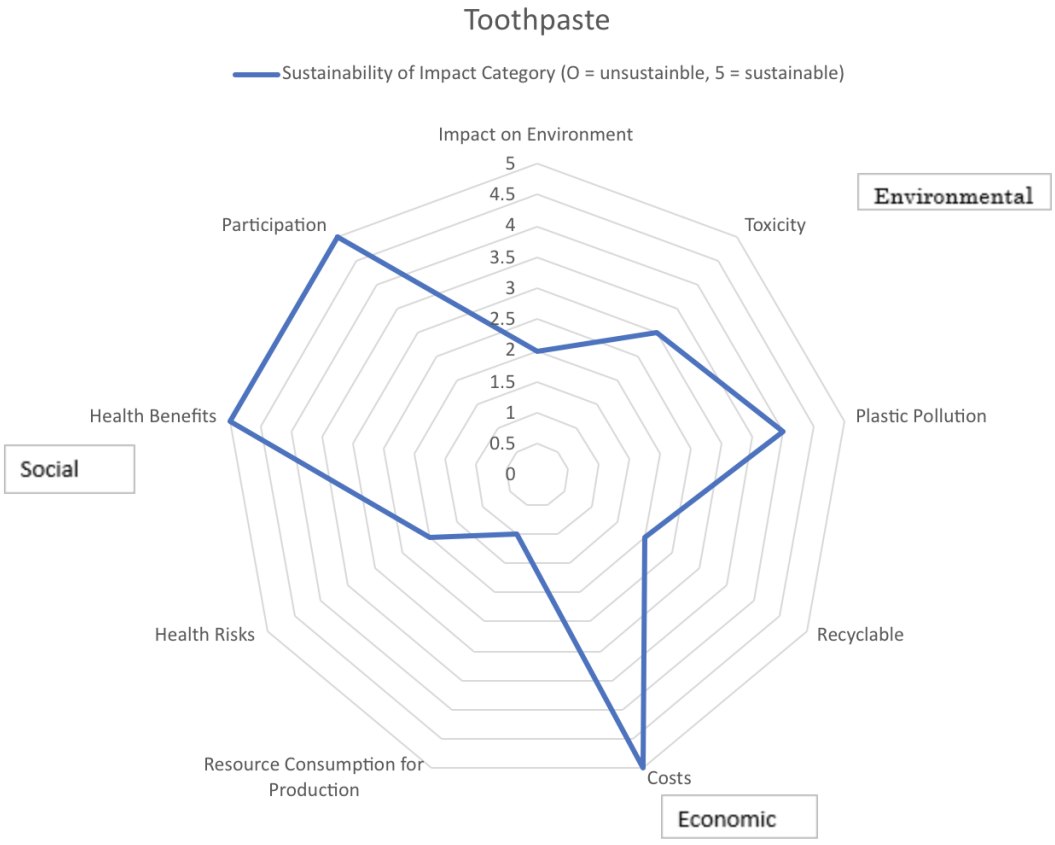

Figure 2. Toothpaste radar plot is demonstrating various levels of sustainability for each of nine impact categories under the pillars of sustainability. It is on a score of 0 meaning unsustainable and 5 meaning sustainable.

3.2.3 Gel Radar Plot

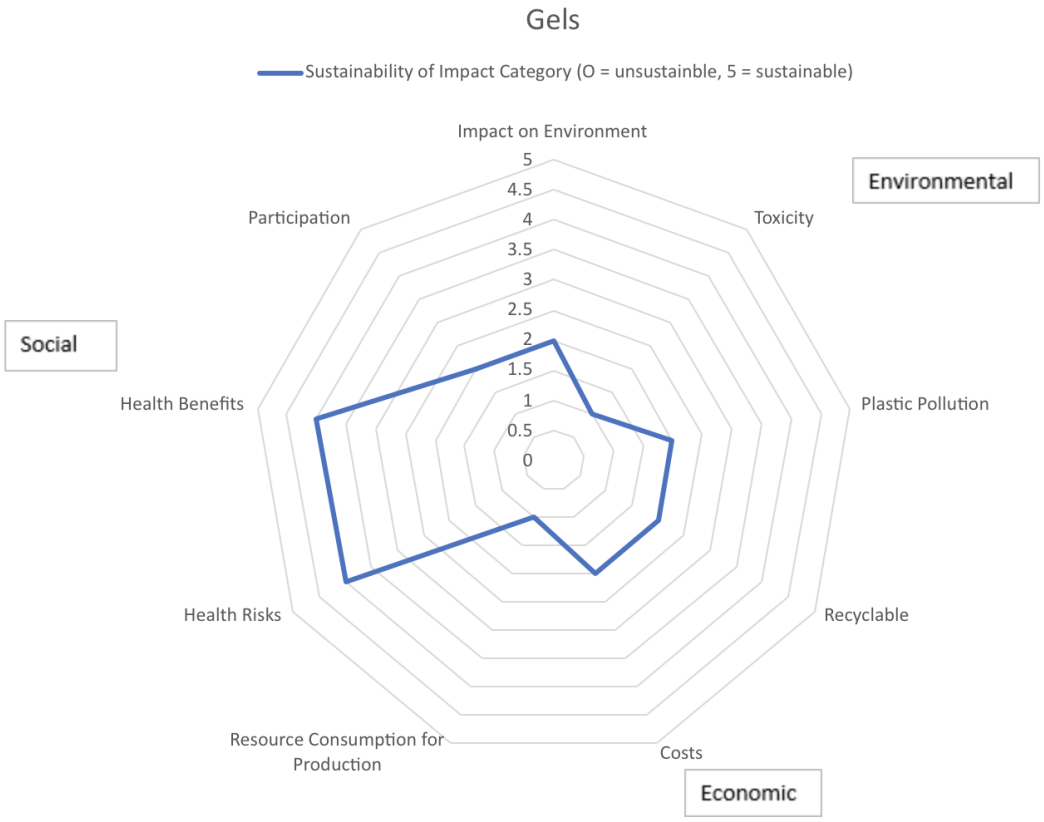

Figure 3. Gel radar plot is demonstrating various levels of sustainability for each of nine impact categories under the pillars of sustainability. It is on a score of 0 meaning unsustainable and 5 meaning sustainable.

3.2.4 Varnish Radar Plot

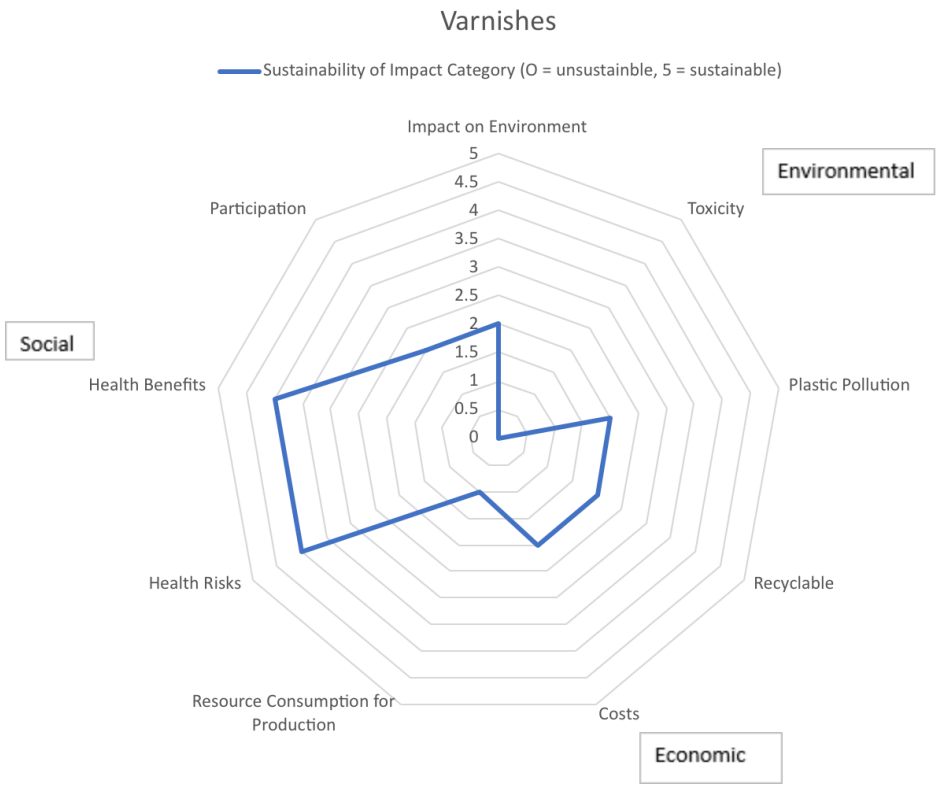

Figure 4. Varnish radar plot is demonstrating various levels of sustainability for each of nine impact categories under the pillars of sustainability. It is on a score of 0 meaning un-sustainable and 5 meaning sustainable.

3.2.5 Foam Radar Plot

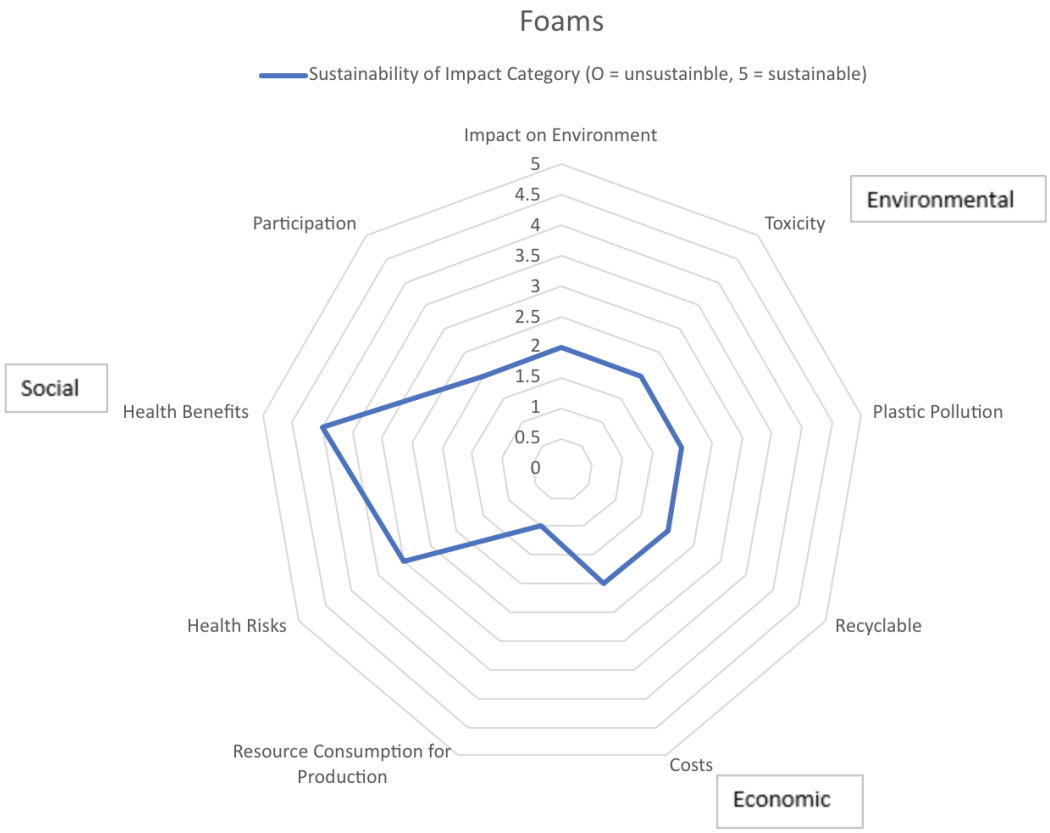

Figure 5. Foam Radar Plot is demonstrating various levels of sustainability for each of nine impact categories under the pillars of sustainability. It is on a score of 0 meaning un-sustainable and 5 meaning sustainable.

3.2.6 Municipal Water Fluoridation

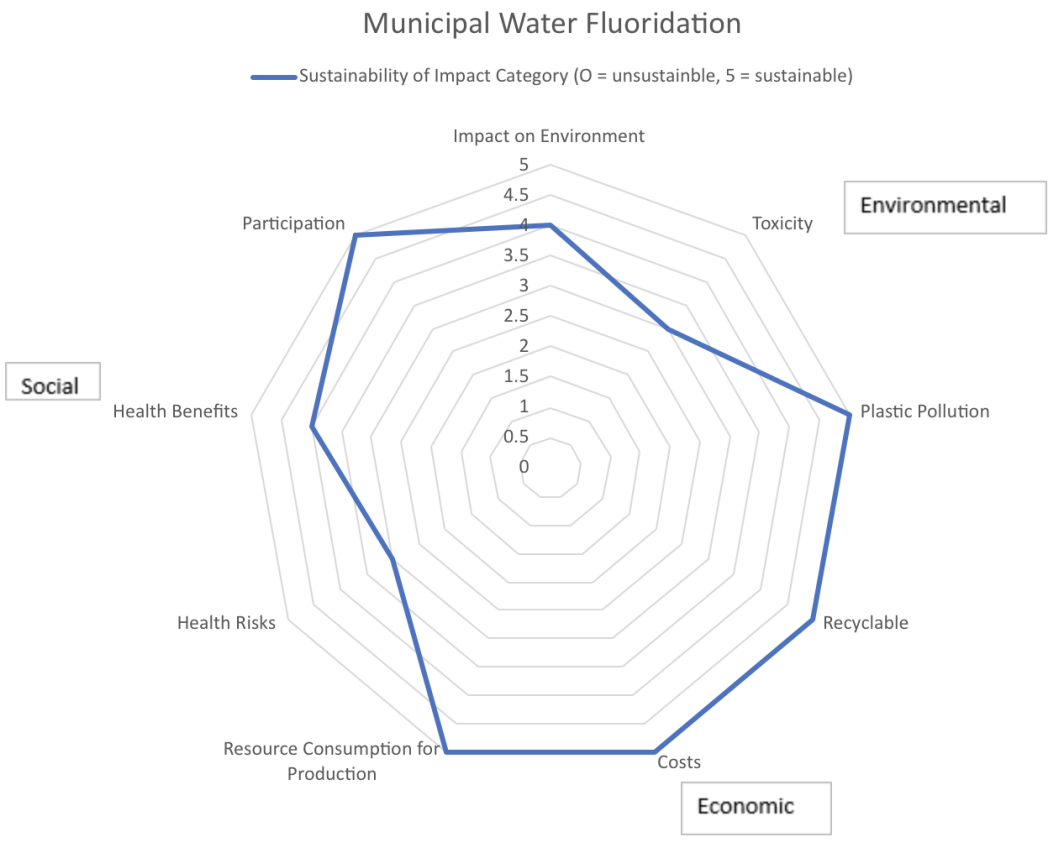

Figure 6. The Municipal Water Fluoridation Radar plot is demonstrating various levels of sustainability for each of nine impact categories under the pillars of sustainability. It is on a score of 0 meaning unsustainable and 5 meaning sustainable.

3.2.7 Bottled Water

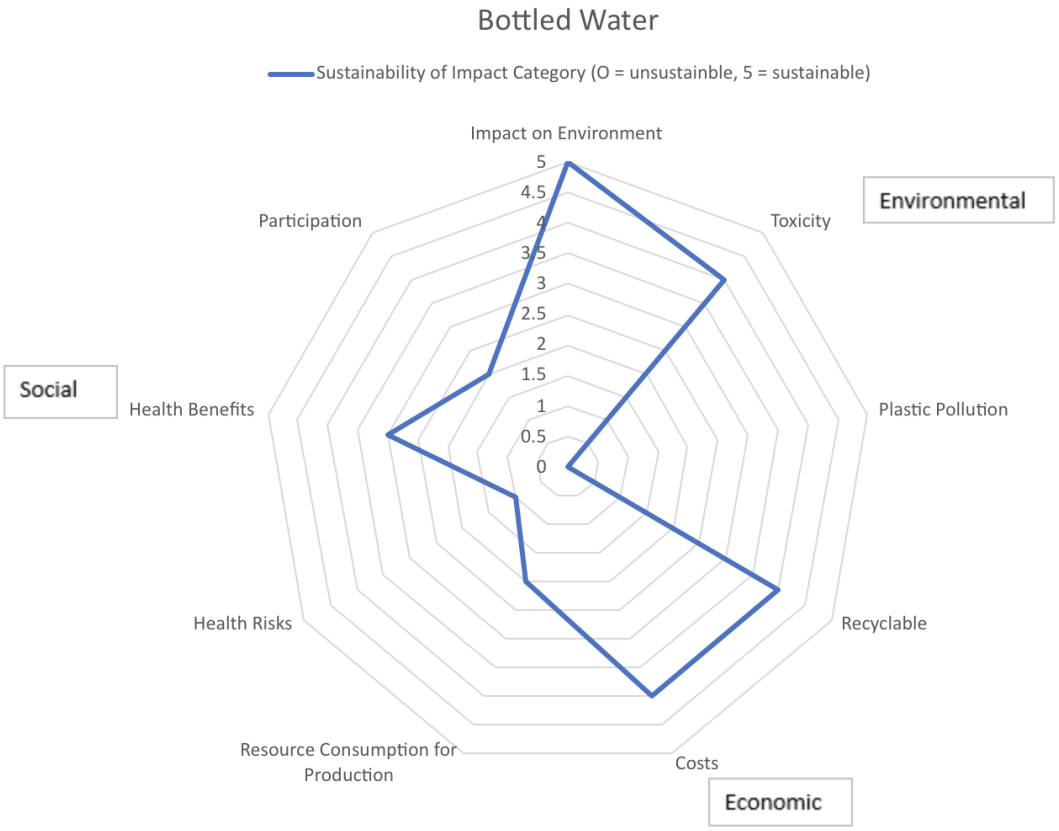

Figure 7. Bottled Water radar plot is demonstrating various levels of sustainability for each of nine impact categories under the pillars of sustainability. It is on a score of 0 meaning unsustainable and 5 meaning sustainable.

3.2.8 Fluoride Supplements

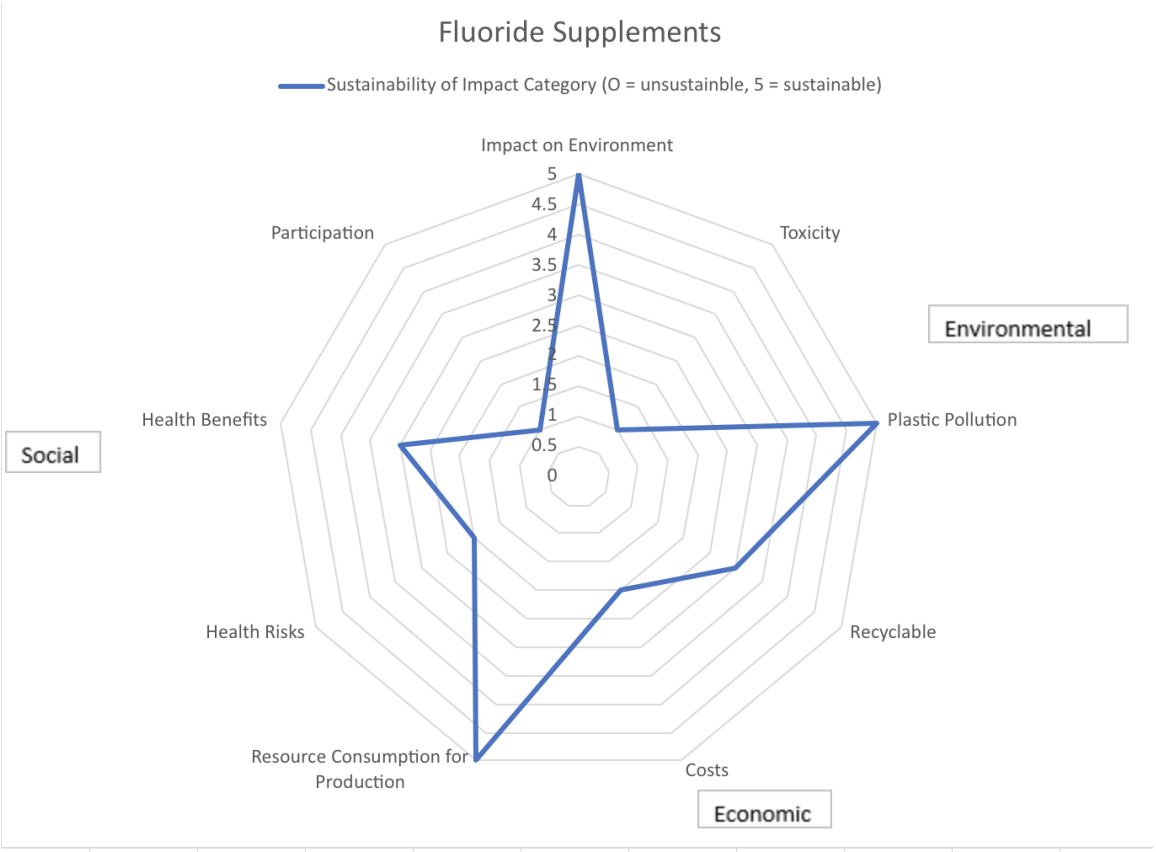

Figure 8. Fluoride Supplement radar plot is demonstrating various levels of sustainability for each of nine impact categories under the pillars of sustainability. It is on a score of 0 meaning unsustainable and 5 meaning sustainable.

4.0 DISCUSSION

4.1 Mouthwash Analysis

The Mouthwash Radar Plot coverage was weighted towards the economic and environmental pillars of sustainability (Figure 1). Mouthwash bottles are made of recyclable plastic. The cost of mouthwash is only 5-15$ per bottle which is an affordable price for most Americans (Table 2). The production for mouthwash requires high use of energy and natural resources since they are produced in manufacturing plants that run on fossil fuels (EDA, 2016). The health risks that come with regular use of mouthwash are average due to the fact that mouthwash can kill all bacteria including the helpful bacteria which disrupts the microbiome and normal function in the mouth (ADA, 2021). On the other hand, mouthwash can kill the bacteria that produce bad breath, in other words halitosis, and can at times clean and reach spots that a normal toothbrush can not (ADA, 2021). Approximately 199.6 million people per year use mouthwash on a normal basis indicating that a moderate amount of Americans participate in the use of mouthwash (Statistica, 2021). Mouthwash bottles have a negative impact on the environment due to the fact that the plastic bottles aren't always recycled and end up in landfills where they won’t decompose for decades (Table 2). Another negative impact on the environment is that the contents can drain into the ocean through the sewage system and cause harm to marine life (Table 1). Since the plastic mouthwash bottles however can be recycled, they have an average sustainability score regarding plastic pollution. The toxicity of mouth-

wash is low to average at 225-450 ppm, unless consumed in large quantities it does not pose a threat, if over consumed an overdose can occur (ADA, 2021). Therefore, mouth-wash poses an average impact on the environment

4.2 Toothpaste Analysis

The Toothpaste Radar Plot coverage was weighted towards the social and environmental sectors of the pillars of sustainability (Figure 2). Toothpaste tubes are not recyclable due to excess product leftover in the tube and the materials that make up these tubes (Table 2). They contribute approximately 400 million toothpaste tubes a year in the United States to plastic pollution (MacKerron, 2021). Although, Colgate just came out with a new tube of toothpaste that is recyclable, which indicates that toothpaste tubes could become more sustainable in the future (MacKerron, 2021). The cost of toothpaste is low at 4$ - 7$ per tube, thus affordable and convenient for most Americans (Statista, 2022). There is high resource consumption for production regarding toothpaste tubes. They are mass produced single-use plastic that requires high levels of energy and natural resources to produce (EDA, 2016). The health risks are average because toothpaste only poses a threat with overconsumption (Veazey, 2021). The health benefits are significant, toothpaste is an essential part of ensuring top tier oral health for the population (ADA, 2021). The participation is high, approximately 307.2 million Americans a year use toothpaste 1-3 times a day in their daily routines (Statistic, 2021). The toxicity of toothpaste is average at 1000-1500ppm (ADA, 2021). The impact on the environment is un-

sustainable because toothpaste tubes are so far not recyclable and thus add more plastic waste to landfills (Table 2). Since the toxicity is low, the health risks are low, cost is low, participation is high, and the health benefits are high, using toothpaste regularly is the best way to use fluoride to improve oral health.

4.3 Gel Analysis

The Gel Radar Plot showed no coverage in which gels were favorably sustainable in any of the three pillars of sustainability (Figure 3). Gel bottles used in professional dental treatments are discarded in the trash since they are not recyclable, which creates plastic pollution in landfills (Table 1). Thus, indicating that they have a negative impact on the environment. The cost of gel fluoride treatments is higher than other non-professional methods of fluoridation at 20$ - 50$ a treatment (MDC, 2021). Fluoride gels are mass manufactured in factories that produce fossil fuels and use up natural resources which in turn harms the environment (Table 2). The health risks with gels are low since they are professionally administered eliminating the risk of overdose and in safe doses (ADA, 2021). The health benefits are high, especially to patients who have low fluoride intake in their daily routines and have a high risk of tooth cavities (ADA, 2021). Participation varies depending on the discretion of dental professionals depending on prior fluoride consumption, age, and current oral health condition (Table 2). The toxicity of professionally applied fluoride gel is more unsustainable than other methods at a value of

12,300ppm (ADA, 2021). If needed, professionals will administer fluoride gels to patients in 3-12 month intervals (ADA, 2021).

4.4 Varnish Analysis

The Varnish Radar Plot (Figure 4) coverage failed to demonstrate a shift towards any of the sectors of the three pillars of sustainability. Varnish containers are not recyclable and create plastic pollution that ends up in landfills. They are produced in factories that consume natural resources, create plastic pollution, and expel harmful pollutants into the environment (Table 2). These three factors cause varnishes to have a negative impact on the environment. The cost of varnish fluoride treatments are higher than other methods of fluoridation at approximately 20$ - 50$ a treatment since they are applied topically by dental professionals (MDC, 2021). The toxicity of varnish is the highest of any other method of fluoridation at 22,600 ppm (ADA, 2021). However, the health risks varnish fluoride treatments pose are low since they are applied by licensed dentists in a professional setting as needed (ADA, 2021). They have average participation since they are applied at dentists discretion in 3-12 month intervals a year depending on factors such as age, current oral health state, and other consumption of fluoride in the patients lifestyle (ADA, 2021). Varnish fluoride treatments are beneficial to human health by preventing tooth decay, especially for those who lack fluoride from other sources (Table 2).

4.5 Foam Analysis

The Foam Radar Plot coverage was weighted towards the environmental and social sectors of the pillars of sustainability (Figure 5). Foam bottles used by dental professionals are not recyclable and thus contribute to plastic pollution in landfills. The cost of them is high to moderate because they are applied in dental offices at a price of 20-50 per treatment (MDC, 2021). High amount of natural resources and energy are consumed in order to produce foams since they are mass manufactured in factories (Table 2). Foams do not pose a high health risk due to the fact that they are applied at the discretion of dental professionals, which lowers the risk of an overdose or overconsumption (ADA, 2021). The health benefits are high when foams are used because the individual most likely needs the treatment due to age or oral health condition at the time of application. Participation is average because foam fluoride treatments are only applied at dental offices where professionals decide how often in intervals of 3-12 months a patient should receive treatment (ADA, 2021). The toxicity of fluoride foam is moderate at 9,040 ppm, giving it a lower sustainability score on the plot (ADA, 2021). The impact on the environment is not sustainable because foam bottles are not recyclable producing plastic pollution and require energy to mass manufacture, which emits fossil fuels into the atmosphere adding to global warming (Table 2).

4.6 Municipal Water Fluoridation Analysis

The Municipal Water Fluoridation Radar Plot coverage was overall higher for all pillars of sustainability compared to other radar plots (Figure 6). Fluoride is directly applied to public drinking water and thus creates no plastic pollution and no cost to the general public (EPA, 2015). It also does not consume many resources for production making it sustainable economically (Table 2). The health risks are average because municipal water comes out of the tap of individuals homes and is used to their discretion. The health risks for municipal water, on it's own, poses no risk due to the low quantity of flouride applied to public water. However, chronic long term exposure to high levels of fluoride in municipal water can potentially lead to health issues such as skeletal flourosis (WHO, 2022). The health benefits are high since it allows for a baseline level of fluoride consumption for the general public which has been proven to lower cavities for the general public, especially for those who do not have access to fluoride in other methods (ADA, 2021). Participation is high at 207.4 million Americans consuming municipal water on a daily basis (CDC, 2018). Most U.S. states in the United States have local officials who decide whether to fluoridate the public water supply or not. If so, then officials follow CDC practices to regulate the quantity applied (EPA, 2015). The toxicity is an average amount at 0.7 mg/L (ADA, 2021). There is no concern regarding municipal waters impact on the environment because the quantity applied is not significant enough to have an impact on the environment along with dilution from other runoff sources (Pollick, 2004) .

4.7 Bottled Water Analysis

The Bottled Water Radar Plot coverage was weighted towards the economic sector (Figure 7). The cost of bottled water is low and therefore affordable for the general public to purchase and consume (Table 2). Water bottles are recyclable, however, the combination of carelessness and convenience make it so that approximately 22 billion water bottles end up in landfills a year which negatively impacts the environment by creating plastic pollution (Table 2). The resource for consumption has a low sustainability value because water bottles are mass produced in large factories that create energy by burning fossil fuels for production which harms the environment (Table 2). The toxicity is low since bottled water only contains 0.11 mg/L of fluoride per bottle (ADA, 2021). The health problems associated with bottled water are low risk due to its low toxicity value (CDC, 2020). The health benefits are average because bottled water does not have a sufficient fluoride content to cause improvement to oral health on its own, but along with other methods it does contribute to create a healthy amount of fluoride in a person's consumption (CDC, 2020). The participation varies highly on the individual, approximately 65.3 million people in the United States use bottled water (ADA, 2021).

4.8 Fluoride Supplement Analysis

The Fluoride Supplement Radar Plot coverage was not weighted towards any of the three pillars of sustainability (Figure 8). Since fluoride supplements are directly ingested, no plastic pollution is created (Table 2). The cost of fluoride supplements are av-

erage around 15$ for 120 tablets (Table 2). The health risks are low since they are prescribed by medical professionals on discretion of current health conditions of the patient (ADA, 2021). The health benefits are high since they are specified for certain patients that have low fluoride consumption from other methods and/or have a high risk of cavities (ADA, 2021). The participation is very rare since most people don't take fluoride supplements unless prescribed by a dental professional (Table 2). There is virtually no impact on the environment since fluoride supplements are a prescription drug that you ingest. The toxicity of these supplements is higher than average non-professional fluoride treatments since it is concentrated fluoride in a tablet of either 0.25, 0.5, or 1.0 mg (ADA, 2021).

5.0 CONCLUSION

Municipal water in its small quantities does not pose a threat to overall human health. However, acute and chronic fluoride overconsumption can occur and would lead to health problems (WHO, 2022). If you are prone to cavities, a combination of fluoridation methods is the best way to strengthen your enamel and overall oral health. The best combination of fluoridation methods to improve oral health is brushing regularly 1-3 times a day, drinking from municipal water on a regular basis, and using fluoride treatments as needed by dental professionals after calculating fluoride that is already consumed on a normal basis to prevent overconsumption. The combination of these methods will maximize health benefits and decrease health risks at the lowest cost. Another condition that needs to occur in order to preserve human health and avoid risks is to create more awareness to the general public so that they can be conscious that are consuming fluoride and in what quantities to avoid overconsumption. By doing this, people can take notes of the ways they are consuming fluoride and let their dentists know when they go and prevent potential overconsumption. In conclusion, municipal water fluoridation alone poses no concern to human or environmental health unless it is over consumed long term.

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