Monitoring Landfill Fires in Armenia

An Interactive Qualifying Project Report

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Abstract

The goal of this project was to create a map of landfills in Armenia that have been on fire during the last five years and to rank the landfills based on criteria determining how harmful they are to nearby communities and the environment. The map and rankings can further be used by the project sponsor to take measures to prevent the negative impact of landfill fires on both the environment and surrounding communities.

Acknowledgments

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Executive Summary

This project focuses on using remote sensing to monitor landfill fires in Armenia, addressing an overlooked aspect of municipal solid waste management. Landfill fires pose significant environmental and health risks, particularly in Armenia, where they are prone to frequent burning. By identifying reliable remote sensor data sources, aggregating data using ArcGIS, and developing a map for landfill risk ranking, the goal is to provide the center with a tool to monitor landfill fire risk more efficiently through the use of industry-standard technologies.

Landfill fires, both surface and subsurface, pose significant environmental and health risks due to poor waste management practices. Surface fires are easier to respond to, while subsurface fires are more challenging to detect because there is no visible flame. Common causes include self-ignition, sparks from machinery, and arson. Subsurface fires may result from increased oxygen and bacterial activity or anaerobic reactions. Various types of waste, including general residual waste, batteries, electronics, paper, cardboard, and other hazardous waste, are susceptible to combustion.

Due to the release of various pollutants such as carbon monoxide, nitrogen oxides, and volatile organic compounds, landfill fires can have negative effects on air quality, surrounding ecosystems, and human health. Exposure to fine particulates, including PM2.5 and PM10, can lead to respiratory issues and premature death. Additionally, toxic smoke and gases emitted during landfill fires can cause symptoms like headaches, nausea, and fatigue.

Armenia faces significant challenges in environmental protection, particularly in waste management and air quality control. Despite the presence of governmental agencies like the Ministry of Health and the Ministry of Environment, inadequate infrastructure and regulations

contribute to poorly managed waste disposal sites and air pollution. The smoke from landfill fires contributes to air pollution in Armenia, also producing gasses containing pollutants such as methane, ammonia, and hydrogen sulfide.

Armenia has 300 landfills that are shared among its 500 municipalities, with each landfill serving two municipalities. None of these landfills meet sanitary norms or have proper engineering, lacking protective layers to prevent toxic liquids from contaminating the soil and groundwater. Landfill fires are a recurring issue in various regions, including Armavir, Kasakh, Spitak, Jrvezh, and Ejmiatsin, posing health hazards due to the release of harmful substances into the atmosphere. Additionally, illegal landfills are prevalent, with regions like Tavush and Gegharkunik having unregistered and improperly managed disposal sites, exacerbating environmental and public health concerns.

The project has three main objectives:

1. Identifying reliable remote sensor data sources that collect fire identification and risk data
2. Aggregating and Visualizing Data Using ArcGIS
3. Developing ArcGIS map and landfill risk ranking for the AUA Acopian Center for the Environment to use to decide what landfills to monitor closer and start to reform

The first objective was fulfilled by finding and using open-source data, specifically, NASA's FIRMS dataset, which is known for its detailed fire information. This dataset combines observations from two main instruments: the MODIS on Aqua and Terra satellites, providing data since 2000 with a resolution of one kilometer per pixel; and the VIIRS on Suomi-NPP, NOAA-20, and NOAA-21 satellites, offering higher-resolution data since 2019 with a resolution of 375 meters per pixel. This system uses satellite images in the visual and infrared spectrums to find areas of high relative brightness, with brightness in the infrared being an expression of temperature. The data is freely available and receives many scholarly reviews, making it a valuable resource for the project.

The second objective was met by combining the NASA FIRMS data with the map of dumpsite locations in Armenia provided by the AUA Acopian Center of the Environment. The time, location, and intensity of these fires were combined with the map of dumpsites using ArcGIS software. All fires inside a dumpsite were flagged as waste fires.

Finally, for the third objective, the number of times the landfill has been on fire and the intensity of fires in each dumpsite, as well as proximity to forests and settlements, were used to calculate a score representing the risk each site posed to the surrounding environment. The top ten sites with the highest scores were compiled into a ranked list. The top three were Nubarashen with a score of 78.00, Goris with a score of 25.40, and Dzoragyugh with a score of 22.81.

The project team determined that the remote sensing techniques used have significant fundamental limitations, and satellite data should be supported with observations taken on the ground, such as visual observation of smoke and air quality readings, and further improvements can be made to the map. Further extensions for the work already done could be the mapping of forest fires or the other environmental impacts of dumpsites, such as leachates, in relation to nearby water sources, or an examination of health impacts from inhalation of smoke, as well as the improvement of landfill infrastructure. These extensions can also be implemented into the formula for the rankings of the landfill fires.

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Chapter 1: Introduction

Municipal solid waste (MSW) management and disposal is an often-overlooked aspect of maintaining a pleasant and healthy living environment. Once removed from living and working spaces, MSW is often neglected and dumped into a landfill with little concern for the long-term environmental consequences. This report will refer to any location where MSW is collectively disposed of as a landfill for the sake of consistency. Though the term landfill implies that the location is specifically engineered to safely accommodate large quantities of MSW, this is not the case for the majority of dumpsites in Armenia, which have no environmental protections in place whatsoever (LL Bolagen, 2020). Specifically, this IQP focuses on using remote sensing to monitor fires that arise in landfills. These fires are a problem due to their heat and greenhouse gas emissions, which contribute to climate change. On top of this, the fumes created by burning plastics and other substances can be toxic and cause illness if inhaled, making landfill fires especially dangerous to communities close to landfill fires. This issue is particularly relevant to Armenia as the country's landfills are prone to frequent burning. On May 18th of 2023, a fire started in the Nubarashen landfill in Yerevan that burned for over ten days, emitting harmful pollutants, with the fire department initially unable to put it out (Ecolur, 2023). There are currently limited resources dedicated to this problem. However, in conjunction with the project sponsor, the American University of Armenia (AUA) Acopian Center for the Environment, this project hopes to help address the challenge of limited resources through both the project itself and future work done by the sponsor expanding the project's scope. The AUA Acopian Center for the Environment aims to promote the protection of Armenia's biodiversity and natural resources through research, education, and public involvement. They are dedicated to studying the environmental impact of human activity on Armenia and utilizing modern information technology such as GIS and remote sensing. This project aims to assist their efforts. Through research, information on waste management practices was collected, including those currently implemented in Armenia and the types of waste found within them. Additionally, how fires in landfills start, how they propagate, and the methods of mitigating them were researched. Context for the state of waste management and landfill use in Armenia, and the monitoring of fires using remote sensing in other countries were covered. Past studies examining relevant problems to our project provided the necessary context to shape our methods. Studies have been completed that used remote sensing data to create maps classifying different aspects of the data. These studies shaped the project team's methods to identify reliable and accessible data sources and use that data in small pilot projects to apply monitoring techniques to landfills in Armenia. Satellite images across the visible and infrared spectrum from multiple satellites are processed by NASA's Fire Information for Resource Management System (FIRMS) and are openly available online. This processed data shows the approximate locations of fires across the Earth's surface stretching back more than five years. This FIRMS data was compared to a preexisting map of landfills in Armenia to identify which sites are on fire over time, both through aggregate and time series forms.

This project assisted the AUA Acopian Center of the Environment in utilizing industry standard technologies, such as ArcGIS and remote sensing data, to monitor landfill fires. Implementing this system allows the center to more easily locate these fires and help inform potential future projects. The following objectives were established to achieve the project's goals:

1. Identify reliable remote sensor data sources that collect fire identification and risk data
2. Aggregate and Visualize Data Using ArcGIS

3. Develop ArcGIS map and landfill risk ranking for the AUA Acopian Center for the Environment to use to decide what landfills to monitor closer and start to reform

Achieving the three objectives of the project would provide the AUA Acopian Center for the Environment with an ArcGIS visual connected to reliable data to monitor landfill fires in Armenia.

Chapter 2: Background

This chapter begins with a discussion on the nature and negative effects of landfill fires. Next, general and model waste management practices are covered, followed by a discussion of what the problem currently is in Armenia. This chapter concludes with a look into the Monitoring Burning Landfills of Armenia project in collaboration with the AUA Acopian Center for the Environment, with the hope that this project can be used to effectively improve the situation regarding landfill fires in Armenia.

2.1 Landfill Fires

Landfill fires, also referred to as waste fires, represent a significant environmental hazard, posing risks to human health and ecosystems. These fires occur at waste disposal sites where combustible materials undergo decomposition, often exacerbated by poor waste management practices. Understanding the types, causes, and consequences of landfill fires is crucial for effective prevention and mitigation strategies. There are two main types of landfill fires: surface and subsurface fires. Surface fires, or fires that occur within the upper 1.5 meters of the landfill (Davis et al., 2021), are usually easier to respond to (Dabrowska et al., 2023). Unlike surface fires, subsurface fires can often be more challenging to detect as there are fewer visible signs of the fire's occurrence (Nazari et al., 2020). The latter is often the most dangerous, as it is harder for emergency services to react to. The fire can often cause structural damage to the landfill (Dabrowska et al., 2023).

The most common cause of landfill fires is self-ignition, though other causes, such as sparks from machinery and arson, are known (Mikalsen et al., 2021; Dabrowska et al., 2023). Subsurface fires can also be due to "increasing oxygen at depth, which increases bacterial activity, resulting in smoldering for weeks to months, and fires if methane is present" as well as through anaerobic exothermic reactions (Davis et al. 2021). While landfill fires are not exclusive to any type of waste, general residual waste is found to be the most susceptible to being on fire. Batteries, electricals and electronic waste, paper and cardboard, and hazardous waste also have a high fire risk, as seen in Figure 1. The figure below shows different materials and the risk of it burning.

Waste fraction, sorted by fire risk	Ignition frequency	Qualitative assessment of potential consequences	Comment to assessment of consequences
General, residual waste	Often	High	Large quantities, damage on equipment, pollutants
Batteries*	Often	-	Depends on waste fraction*
Electrical and electronics waste	Regularly**	High	Pollutants
Paper and cardboard	Regularly**	High	Large quantities, damage on equipment
Hazardous waste	Rarely	High	Pollutants
Wood waste	Regularly	Medium	Large quantities
Park and garden waste	Regularly	Medium	Large quantities
Plastic waste	Rarely***	Medium	Energy density, pollutants
Rubber	Very rarely	Medium	Energy density, pollutants
Organic waste	Rarely	Low	None stands out
Discarded vehicles	Rarely	Low	None stands out
Metal	Rarely	Low	None stands out
Sludge, mud	Rarely	Low	None stands out
Slag	Rarely	Low	None stands out
Glass	Very rarely	Low	None stands out
Slightly con-taminated masses	Very rarely	Low	None stands out
Concrete/ bricks	Very rarely	Low	None stands out
Textile	Very rarely	Low	None stands out

* All battery-related fires included. Batteries are not a separate waste fraction, but are highlighted in this table to show their inherent fire risk.
** Not as frequent in Sweden as in Norway
*** Not as frequent in Norway as in Sweden, where recycled plastic (bales) regularly cause fires

Figure 1: Total Assessment of Fire Risk for Different Waste Fractions (Mikalsen et al. 2021)

As landfills contain a mixture of solid wastes that are shown in Figure 1, there exists a plethora of thermal characteristics and conditions within landfills that can make them susceptible to spontaneous combustion. Spontaneous combustion is also influenced by moisture content, oxygen concentration, temperature, and the presence of catalysts (Moqbel et al., 2010).

Landfill fires can have a variety of negative effects, from air pollution's effect on the health of the surrounding people to the environmental impacts caused by the fires. Not only can landfill fires negatively affect nearby waterways and the surrounding soils (Dabrowska et al., 2023), but they can also affect the air quality of a region, often introducing carbon monoxide and dioxide, nitrogen oxides, hydrochloric acid, hydrogen cyanide, volatile organic compounds, persistent organic pollutants, ketones, aldehydes, and black carbon to the atmosphere (Dabrowska et al., 2023). Exposure to fine particulates such as PM 2.5 (particles smaller than 2.5 microns in diameter [e.g. black carbon]) and PM 10 (particles smaller than 10 microns in diameter) emitted by the landfills, are associated with premature death and harmful effects on the respiratory system as the fine particulates can cause damage to the lungs when inhaled (Brown, 2013). On top of this, landfill fires can produce toxic smoke and gas, which can result in headaches, nausea, and fatigue (Dabrowska et al., 2023). The dispersion of PM 10 is especially notable, as it has a significant association between the relative risk of death and its concentration (Bihalowicz et al., 2021). Other chemicals released while burning plastic include benzo(a)pyrene and polyaromatic hydrocarbons, which have both been shown to cause cancer (*Environmental and health impacts of open burning*). These negative effects, ranging from headaches and nausea to death, are significant enough to warrant concern from everyone. Thankfully, through proper waste management techniques, it can be possible to mitigate landfill fires and therefore mitigate their consequences.

2.2 Waste Management Around the World

Common practice is to first collect waste, by which there are multiple methods. The simplest option is to not bring waste to a landfill at all. This is most common in rural areas and involves the burying or open burning of waste within the residence where it was generated. In more developed areas, the local government collaborates with a subcontractor company to pick up waste curbside at residences, or in dumpsters outside commercial or industrial locations. This service requires a fee, which can encourage disposing at unregulated illegal dumpsites. Waste is typically mixed when collected, with all different categories of waste combined.

There is an important distinction to make between the terms landfill and dumpsite. Landfill implies that the site is specially designed and built for waste disposal, with safeguards to prevent pollutants escaping and to prevent spontaneous fires as described in the following section. Dumpsites by comparison have little to no construction work done to accommodate for waste disposal (LL Bolagen, 2020). Most if not all waste disposal sites in Armenia fall under the category of dumpsite and not landfill.

2.2.1 Ideal Practices in Waste Collection and Disposal

Best practice for waste collection begins when it is first generated. Ideally, waste is sorted when it is initially thrown out by the general public before collection, with organic waste, recyclables, and hazardous materials such as electronics and chemicals separated for composting, recycling, and specialized storage, respectively. Specifically designed destination facilities have some means of measuring the amount of waste brought in, typically through weighing visiting vehicles. Sites that have the best practice are fenced off from animals and have staff present to ensure waste is being dumped in the right locations. Incoming waste goes through a second round of manual sorting by the waste facilities to remove items missed during pre-collection sorting. Waste is then compacted to save space, which has the added benefit of limiting the amount of oxygen that can infiltrate below the surface, starving potential fires. Layers of waste are covered with soil to prevent pieces from being blown away and to further prevent oxygen infiltration. (Bolton, 2019).

2.2.2 Waste Management in Armenia

As of 2020, nearly all waste in Yerevan is collected and brought to a landfill. Outside Yerevan only 70% of waste is collected, the rest being disposed of at the residence or dumped at illegal dumpsites (LL Bolagen, 2020). The collected waste is mixed and dumped without being sorted. There are no measurements or records of waste being brought into the landfills. The LL Bolagen study analyzed the composition of the mixed waste coming into Armenia's landfills, shown in Figure 2.

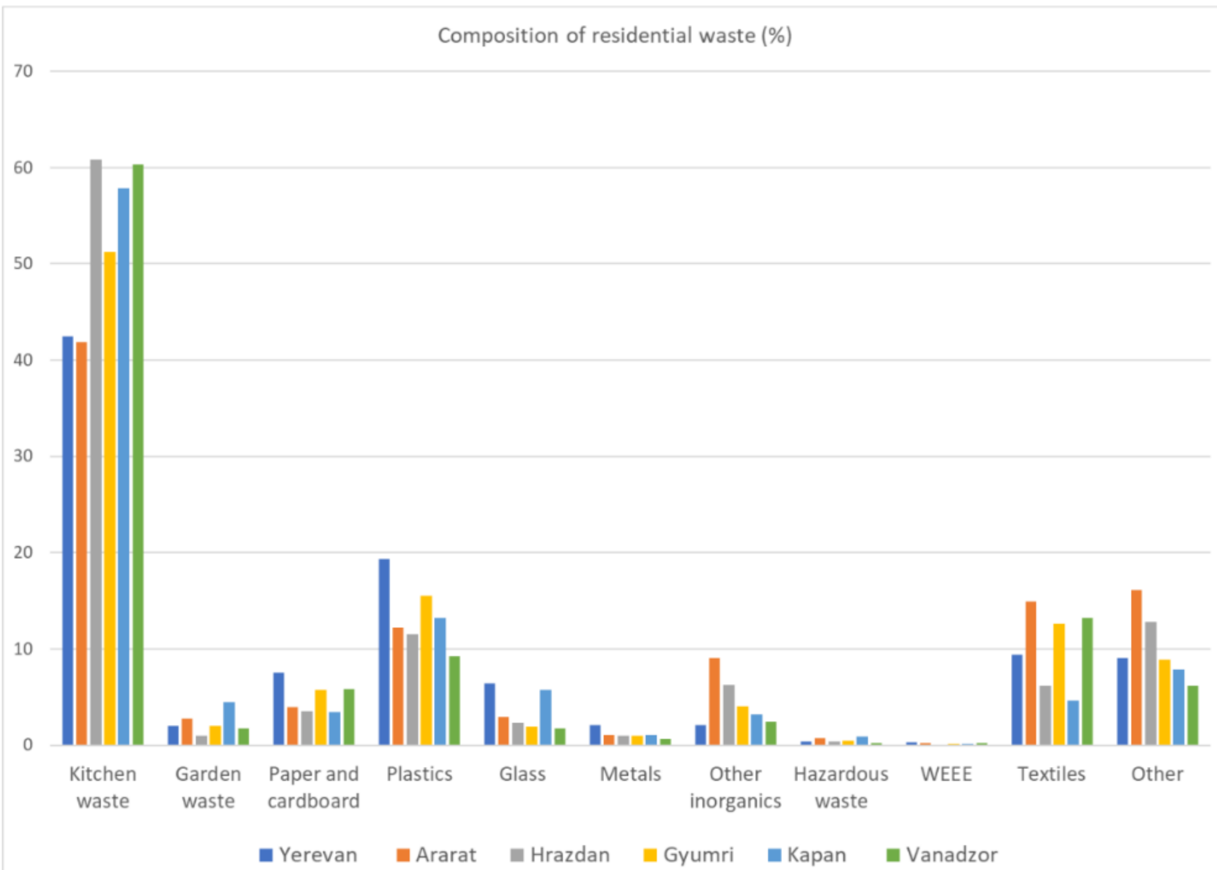

Figure 2: Percent composition of waste in six of Armenia's landfills (LL Bolagen, 2020)

The majority of the waste in these landfills consists of flammable matter. The plastics, hazardous waste, and WEEE (waste from electrical and electronic equipment) categories are also especially hazardous when they burn due to the fumes created (LL Bolagen, 2020).

2.3 Environmental Problems in Armenian Landfills

Armenia faces significant challenges in the realm of environmental protection, with deficiencies in waste management and air quality control contributing to its status as a less developed nation in these aspects. The Ministry of Health and the Ministry of Environment are governmental agencies dedicated to addressing these issues (Ministry of Environment, 2024). Despite these agencies, the country struggles with inadequate infrastructure for handling waste, resulting in poorly managed disposal sites that pose risks to both the environment and public health (Ecolur, 2019). The issue extends to air pollution, as Armenia contends with insufficient and inaccurate measures to address emissions and industrial pollutants. The lack of effective policies and investments in sustainable practices such as the lack of landfill regulations underscores the urgent need for comprehensive environmental initiatives. Addressing these shortcomings is pivotal not only for mitigating immediate environmental hazards but also for fostering a more sustainable and resilient future for Armenia. For example, the government could add more regulations and ways of waste management such as sorting the trash (*Rubbish or Waste? What Is Recyclable in Armenia?*, 2021).

2.3.1 Air Pollution

According to an Armenian news agency Armenpress, in August 2022, the level of air pollution in Yerevan reached the red zone of the Air Quality Index, which means the air pollution levels are dangerously high, with adverse health effects on the general public. As Deputy Director of the Hydrometeorology and Monitoring Center, Gayane Shahnazaryan, mentioned in their monitoring, the most polluted areas in Yerevan were Arshakunyats Avenue and the vicinity of the

Circus (Gaboyan, 2022). Additionally, other cities such as Vanadzor, Alaverdi, and Gyumri experienced notable dust pollution, occasionally surpassing permissible concentration levels. Nitrogen dioxide levels in Yerevan, particularly around the Circus area, exceeded acceptable limits, with fluctuating data observed across different parts of the city. The Director of the Yerevan Department of the Environment and Subsoil Inspection Agency, Armen Lablajyan, attributed the pollution to factors such as the ongoing construction boom, mining activities within Yerevan, and inadequately covered transportation of materials like sand. (Gaboyan, 2022) The main pollutants in the air are dust, including PM 10 and PM 2.5, carbon monoxide, nitrogen oxides, sulfur dioxide, tropospheric ozone, heavy metals, and evaporating organic materials. (Sargsyan, 2023). Landfills produce gas, which contains many different pollutants. Methane and carbon dioxide typically make up 90 to 98% of landfill gas, and the remaining 2 to 10% mainly consists of nitrogen, oxygen, ammonia, sulfides, hydrogen, and various other gasses (New York State Department of Health, n.d.). Landfill gases are produced when bacteria break down organic waste, which is called bacterial decomposition. Dust particles can be generated from activities within landfills, such as the disposal and handling of waste. NOx emissions can result from the combustion of waste materials, including the burning of landfill gasses. Landfills can be a source of heavy metals if they contain electronic waste, batteries, or other items with metal components. Leaching of heavy metals from disposed materials is a concern. Volatile organic compounds (VOCs) may be released from decomposing organic waste in landfills. (*ATSDR - Landfill Gas Primer - Chapter 2: Landfill Gas Basics*, n.d.) Ammonia and hydrogen sulfide are responsible for most of the odors at landfills. Methane is flammable and concentrations have sometimes exceeded explosive levels indoors. (Important Things to Know About Landfill Gas, n.d.)

2.3.2 Armenian Landfills

Armenia currently has 300 landfills and 500 municipalities. This is a high number for such a small country like Armenia. None of the 300 landfills meet the sanitary norms, and none of them were engineered properly.

According to the Hydrometeorology and Monitoring Center, there have been and still are landfill fires in the main landfills of the following regions: Armavir, Kasakh, Spitak, Jrvezh, Ejmiatsin, Garni, Byureghavan, Yeghvard, Metsamor, and Abovyan (Landfill Exploration, 2024). A news article states that the region of Tavush has two main unregistered landfills: one near Dilijan and another near Berd (Hovhannisyan, 2015). The one near Berd is usually burned to get rid of the garbage. The one near Dilijan is usually disposed of into the river Aghstev, which is illegal. People who live there also dispose of their trash into the river, despite many signs saying that it's forbidden. There is also landfill information about the Gegharkunik region, and according to a news article in Hetq, the number of landfills there is fourteen, nine of which are illegal (Hovhannisyan, 2016).

According to Ecolur, which is an Armenian environmental news agency and online platform focusing on environmental issues and developments in Armenia, on May 18, 2023, a fire broke out in Yerevan's Nubarashen landfill, releasing substances harmful to health into the atmosphere (Ecolur, 2023).

2.4 Monitoring Landfill Fires

Studies in various countries have been completed on monitoring fires using remote sensors. The term remote sensing is used to describe any kind of observations gathered at a distance from the site being studied, though in most cases, remote sensing refers to the use of satellites for data collection. Satellites are a preferred method for remote sensing because of their ability to view large portions of the Earth's surface at set intervals for years, making for large quantities of reliable data. Some Earth observation satellites operated by government agencies like National Aeronautics and Space Administration (NASA), United States Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), and European Space Agency (ESA) have had their data made publicly available at no charge. These data sets have been used extensively in past studies and will be useful for monitoring the landfills of Armenia for the project (Papale et al., 2023).

The most commonly available and highest resolution data type available is images in the visible spectrum. Plumes of smoke and sometimes even the flames themselves are easily visible in the case of surface fires, though subsurface fires, which are more important to monitor, are impossible to detect using this method if they do not produce smoke. Smoke can also be difficult to identify against snow cover or clouds, and the target area could be covered by clouds completely. An appealing alternative to the visual spectrum is observing in thermal infrared. In this way the heat from a fire can be detected directly. Cloud cover is still an issue and sufficiently deep fires don't heat the surface enough to be detected. Another signature of fire, greenhouse gasses (GHGs) such as carbon monoxide and methane in the atmosphere can also be sensed by satellites. Unfortunately, the spatial resolution of such measurements is in the order of kilometers, making them too inaccurate to measure specific landfill sites. These gasses can also be produced regardless of a fire.

2.4.1 Case Study: Remote Sensing for Internal Temperature of Landfill Monitoring

In 2021, Nazari et al. presented a study on methodologies for "remote satellite monitoring of the location and movement of subsurface thermal events within landfills" (Nazeri et al., 2021).

While previous studies have shown that it is possible to map and monitor landfills through remote sensing technology by looking at the difference between baseline surface temperatures and their surroundings, Nazari et al.'s study was the first to use remote sensing data to attempt to monitor landfill health and the potentiality of subsurface landfill fires. In the study, they applied their methodologies for subsurface thermal monitoring to the Bridgeton Sanitary Landfill in Bridgeton, Missouri. The Bridgeton, Missouri landfill has a leachate collection system. The study employed data from thermal infrared sensors onboard Landsat satellites. These sensors pierce the landfill's surface, detecting telltale heat signatures indicative of potential subsurface fires. Through collecting and cleaning the data from 2000 to 2016 they gathered a group of images corrected for atmospheric interference. Then the images were processed in MATLAB to analyze the thermal data, allowing them to find hotspot anomalies, as shown in Figure 3.

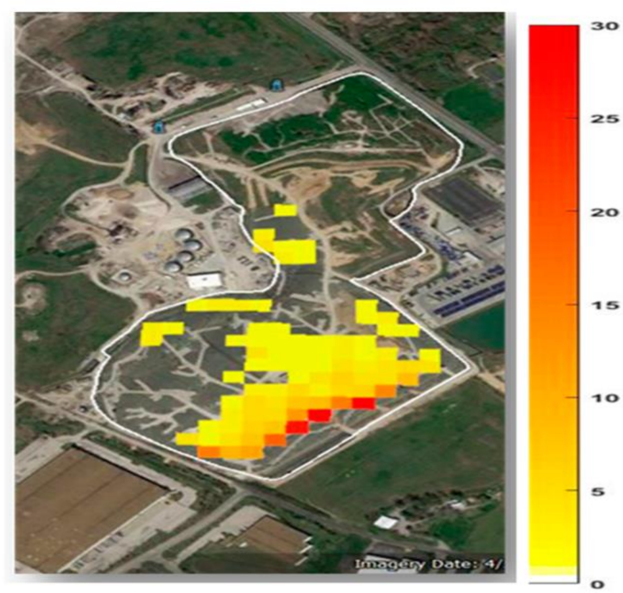

Figure 3: Peak temperature frequency heatmap for the Bridgerton landfill (Nazeri et al., 2021)

Figure 3 shows the locations that reached the highest (or near-highest) temperature values most frequently. The bar on the right indicates the number of highest temperature occurrences at that spot. By finding out which areas have the highest internal temperature over time, the researchers can use this information to predict where internal fires are likely to occur. Through the comparison of past data with new data, it can also be possible to discover new hot spots when they occur. Through their research, Nazari et al. provides a model for the use of remote sensing to monitor subsurface landfill fires by using historical data compared with new data to pick up on anomalies and monitor subsurface hotspots that may develop into landfill fires. This study provides a guideline of what can be achieved using remote sensor data.

2.4.2 AUA Acopian Center for the Environment

The AUA Acopian Center for the Environment is a research center focused on promoting the protection and restoration of the natural environment through research, education, and community outreach. To simplify their approach to such a large topic, they have four main interests. These interests are environmental policy, sustainable natural resource management, built environment and natural environment, and information technology and the natural environment (About). The project relates to the last goal of information technology and the natural environment, as this goal emphasizes using technology to better understand the environment.

The integration of information technology into waste management and monitoring has expanded the opportunities in the field of research. The tools the AUA Acopian Center for the Environment aims to implement are GIS, remote sensing, machine learning, and AI (IT and Environment). These tools assist researchers in collecting, visualizing, and analyzing data. GIS is a geographic information system that enables the user to connect data to a map for visualization to understand patterns and relationships in the context of geography (What is GIS?). This is particularly helpful because maps are digestible to the general public, so the inclusion of maps in reports allows for complex ideas to be understood by the audience and spread awareness to the general public. GIS pairs well with data gathered with remote sensing. NASA defines remote sensing as “acquiring of information from a distance” (Earth Science Data Systems). Typically, the collection of data is done via sensors on satellites orbiting the earth. The data gathered requires processing before becoming usable, but once this is done, the data can be applied to a variety of applications (Earth Science Data Systems), one of which is monitoring the environment, particularly wildfires. This idea is presented in the case study of the internal temperatures of landfills. Researchers can use this data not only to visualize it using GIS, but also to train machine learning (ML) and AI models. Machine learning (ML) and artificial intelligence (AI) can generate predictions that inform environmentally sustainable decision-making. An application of this is real-time CO_2 atmospheric concentration, monitoring methane emissions, and tracking air quality (How Artificial Intelligence is Helping, 2022). The AUA Acopian Center for the Environment has begun to implement these technologies into their research.

The AUA has completed projects using GIS and remote sensing. Two projects that they have completed utilizing remote sensing are land-cover and land-use in the Voghji River Basin and forest fire mapping. In both projects, the AUA GIS and Remote Sensing Lab used freely available Sentinel-2 satellite data from the Copernicus program to create map visuals. Researchers were interested in whether accurate results could be obtained using this free, but low-resolution data. The projects resulted in colored maps showing different aspects of the area, such as affected areas from fires and what land is used for as shown in Figure 4 (Schlaffer et al., 2018).

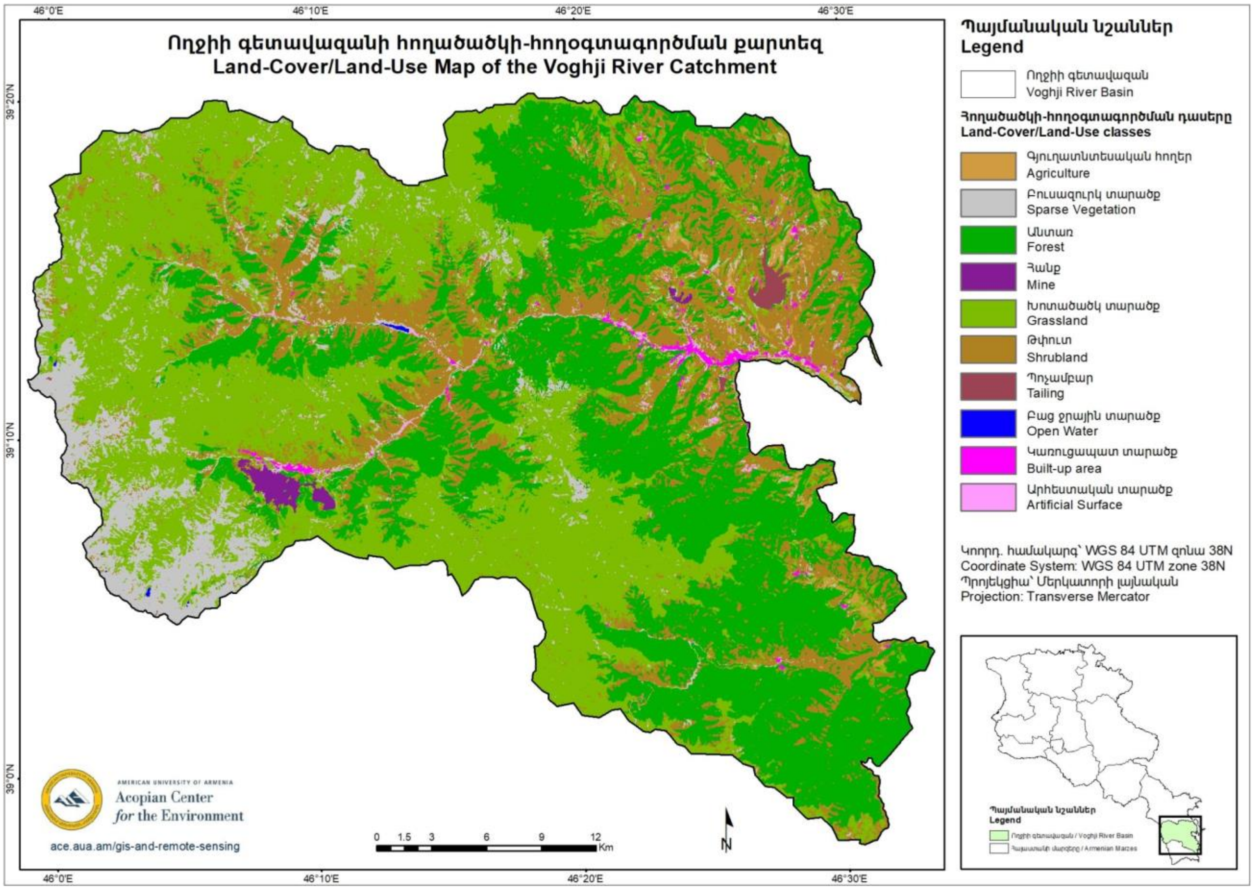

Figure 4: Final map produced by using Sentinel-2 data and classification technique to identify land use in the Voghji River Catchment

The land use report found that their classification of the satellite imagery was accurate despite the low resolution of the images (Schlaffer et al., 2018). This data and higher resolution data can be used in future projects to increase the accuracy of the image analysis and draw conclusions from the remote sensor data. The monitoring of landfill fires project aimed to draw accurate results similar to those of these two projects using remote sensing data.

2.4.3 Overview of the Project

Using past experience from the AUA Acopian Center for the Environment and research from other landfill monitoring case studies, the project team aimed to utilize remote sensing data to map, analyze, and monitor landfill fires. Using techniques from other projects done by the AUA GIS and Remote Sensing Lab, the team applied them to the environmental issue of landfill fires in Armenia. Given the limited existing research on this subject, this project laid the foundation for future landfill reformation and impact studies.

2.5 Summary

Landfill fires pose significant environmental and public health hazards worldwide, including in Armenia, where the approximately 300 waste dumps officially used by municipalities often experience frequent and uncontrolled burning incidents. Despite the prevalence of these fires, there is a notable absence of systematic tracking, monitoring, and assessment of the pollutants. This lack of comprehensive data inhibits effective mitigation and management strategies, exacerbating environmental degradation and endangering public health. The successful remote sensing of these fires through ArcGIS and its subsequent data visualization can help the AUA Acopian Center for the Environment to further their important research in protecting the environment and the health of the country and people of Armenia. With the project completed, the AUA Acopian Center for the Environment will be able to choose what landfills to focus their resources towards to mitigate the effects of landfill fires on local community health.

Chapter 3: Methods

The methods are informed by the three project objectives listed below that were created to achieve the goal of monitoring landfill fires by utilizing remote sensing and ArcGIS for the AUA Acopian Center for the Environment:

1. Identify reliable remote sensor data sources that collect fire identification and risk data
2. Aggregate and Visualize Data Using ArcGIS
3. Develop ArcGIS map and landfill risk ranking for the AUA Acopian Center for the Environment to use to decide what landfills to monitor closer and start to reform

The identification of reliable remote sensing data sources was instrumental in this project. The visuals and analysis performed become irrelevant and misinformative if the data is inaccurate. This would spread misinformation and negatively affect decision making. For this reason, the first objective of this project was to identify accurate and reliable remote sensor data. The second objective of aggregating data using ArcGIS would create ease of access for the users. Data exists across multiple sources, so aggregating it into one map would save the users the effort of finding all the data themselves. Additionally, the aggregated data allows for the users to see patterns that are present. The final objective is to create a landfill fire risk based on the risks the fire poses to the surrounding community and environment based on our map. This would aid the AUA Acopian Center for the Environment in deciding on which landfills to monitor and start reforming.

3.1 Identification of Reliable Data Sources

In this project we researched a variety of different remote sensing tools and recorded different attributes of these tools. This information was necessary to make the best decision for what data source to use. Attributes of the satellites are site revisit time and resolution of different data types. These attributes provided understanding to the pros and cons of each satellite. Consultations with Professor Aghavni Harutyunyan, an GIS expert with AUA, guided which data source was ultimately used, providing advice on both GIS platform options (ArcGIS, GEE, e.t.c) and open source data (landsat, NasaFirms).

For this project it was decided to use open source data. Open source data is available to use free of charge, so funding is not a limiting factor. Since open source data is available to many people, it receives a large amount of review and has supporting materials for its usage such as documentation and external guides. Comparatively, closed source data is only available by payment. Closed source data is typically of a higher resolution and processing quality, and users may receive personalized support so that it can stay competitive with free options. Specifically, we will mostly be using data from the open source NASA's FIRMS dataset. This data set provides a high resolution and the best remote sensing fire identification data. This consists of observations from two different instruments. The first is the Moderate Resolution Imaging Spectrometer (MODIS) instrument aboard the Aqua and Terra satellites, which have a spatial resolution of one kilometer per pixel and a temporal resolution of one day, with observations beginning in 2000. The Aqua satellite focuses on observing Earth's water cycle, including precipitation and evaporation, while the Terra satellite primarily monitors Earth's land surfaces and atmosphere. The second is the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the joint polar satellite system consisting of the Suomi-NPP, NOAA-20, and NOAA-21 satellites with a spatial resolution of 375 meters per pixel and temporal resolution of 12 hours, with observations beginning in 2019.

3.2 Landfill Fire Visualizations

To successfully map the landfill fires of Armenia, ArcGIS was used to map fire data of the landfills in Armenia over time. Fires are identified from this data by identifying areas with a high relative brightness in the visual and infrared spectrum. In the infrared range, image brightness is a direct measure of land surface temperature (LST). FIRMS uses image classification algorithms to filter out clouds and other false positives as detailed in a report from the University of Maryland by Wilfrid Schroeder and collaborators. The commission error, which is the rate of fire misclassification, was determined to be 1.2 percent (Schroeder et. al., 2016). The commission error rate is the rate at which the algorithm deems a fire is present when none exists. The integration of this fire data with other online open source remote sensing information, such as smoke imagery, wind direction, and air pollution enhances the accuracy and effectiveness of fire detection and monitoring strategies. By leveraging the detailed information provided by these datasets, anomalies indicative of landfill fires can be identified. The availability of these open-source datasets empowers researchers and environmental agencies to conduct comprehensive analyses of landfill fire dynamics, enabling proactive measures to mitigate environmental degradation and safeguard public health. By being able to identify and analyze fires, the AUA Acopian Center for the Environment can deduce which landfills would be the best to start to enact mitigation practices. This project utilizes NASA FIRMS; however, a more developed map could be created with other relevant data sources, such as higher resolution satellite data or wind direction to increase accuracy and understanding of the landfills.

3.2.1 ArcGIS

ArcGIS, developed by ESRI, is a geographic information system (esri.com) software suite used for creating, managing, analyzing, and visualizing spatial data. GIS connects data to a map, integrating spatial data with all types of descriptive information (What is GIS?), which helps one to understand patterns, relationships, and geographic context (What is GIS?). ArcGIS represents geographic datasets as a series of dynamic, stacking map layers (Harder & Brown, 2017). These layers can represent a plethora of data, from vegetation health to demographic data. This allows one to visualize their data spatially). In this project, the team used ArcGIS in conjunction with NASA FIRMS data to create a multivariate (multiple variables) map of fire and landfill location data. Landfills in the map that have corresponding data indicating a fire, are labeled as such. One map utilizes time-series data to show how the fires change over time in each landfill, while another creates an aggregated visual of these fires over the past 5 years. The aggregated statistics that were recorded was the number of times the landfill caught on fire and the maximum fire radiative power.

3.2.2 Data Aggregation in ArcGIS

The map was created by overlaying NASA Firms fire identification data from the past 5 years with a map of the landfills in Armenia provided by the AUA Acopian Center for the Environment. Then a spatial join was done to only keep the fires that were inside of the polygons of the landfills or within 350 meter radius to account for the fire location error by the satellite (Ibrahim, 2020). The data was cleaned to ensure that the date acquired of the fires were different, to ensure not double counting of the fires. With this done, two visuals were created, a time series of all the landfills and a five year aggregate map using the aggregate feature in ArcGIS.

3.3 Ranking Fire Risk of Landfills

The final deliverable was an aggregate map, a time series map, and a ranking of landfill fire risk developed from the insights gained by those two maps of which landfills most impacted communities. Landfill fires that are close to villages and forests pose higher risk towards those communities and start forest fires. Additionally, the number of times the landfill has caught on fire in the past five years and the maximum fire radiation power were considered in the ranking. A study done in Turkey ranking forest fires based on similar characteristics was used as a baseline for the fire risk of landfills formula. For each attribute they assigned a unique weight to generate a total risk score (Çolak and Sunar, 2020a). The formula for the risk score that was created is as follows: $R = C*(3 + S + F) + FRP$. In the formula R is risk score, C is count of fires, S is a boolean value of 1 if the landfill is near a settlement and 0 if it is not, F is a boolean value one if the landfill is near forest and zero if it is not, and FRP is the maximum fire radiative power of the landfill in the past five years. This formula was created to emphasize the number of times the landfill has caught on fire, while still valuing fire radiative power. The developed map and rankings will better illuminate the issue of landfill fires in Armenia and generate more awareness to the public. With the project team's work, potential further research in policy reform, air quality, and the costs to human health caused by the fires can be implemented.

Chapter 4: Results

By following the methods of the project, valuable results were obtained. An analysis of satellite data sources was completed that justifies the choice of the NASA FIRMS VIIRS data and can serve as a reference for future remote sensing projects. The created visuals revealed seasonal trends with landfill fires and aided the ranking of landfill fire risk. The rankings of the landfills present the ten most relevant landfills to address in future projects to measure community impact and implement landfill monitoring techniques.

4.1 Reliable Satellite Data Sources

This project first aimed to identify reliable data sources. Several open-source data sets are freely available online from various sources. Table 1 shows several satellite data sources available to use during this project.

Table 1: Comparing Earth observation satellites usable for this project

Spacecraft	**Instrument**	**Revisit time**	**Visual**	**Infrared**	**GHGs**
Landsat-8/9	OLI/TIRS	16 days	30m	30m	-
Sentinel-2	MSI	5 days	10-60m	-	-
Sentinel-5p	Tropomi	<1 day	7000m	7000m	7000m
JPSS	VIIRS	1 day	375-750m	375m	-
Aqua/Terra	MODIS	1-2 days	250-1000m	1000m	-
PlanetScope	Dove	1 day	3m	-	-

The spacecraft and specific instrument names are used interchangeably when looking for data, so it is beneficial to know both when researching them. The revisit time is how often the satellite can see the same point on Earth’s surface and is sometimes referred to as the temporal resolution. Lower revisit time is more desirable, although some landfill fires can last for weeks or even months. The last three columns report the resolution of each instrument. The standout choice for visual spectrum images is PlanetScope, with a resolution of only 3 meters on the surface. Unlike the others, PlanetScope data is not open-source and is only available through the sponsors at the AUA Acopian Center for The Environment. For infrared observations, the best choices for resolution are Landsat-8 and 9, though they suffer from revisit times of over two weeks. High resolution is important for monitoring small landfills, as they can be easily missed at lower resolutions. The final column is GHGs, or greenhouse gasses, which are emitted by fires, such as methane, carbon monoxide, and carbon dioxide. Unfortunately, the highest resolution available for detecting these gasses is 7000 meters, far too broad to accurately associate to a single landfill. This data could be useful if the predictive modeling approach is used. This refers to the method of analyzing patterns observed from known past fires and searching for these patterns to find otherwise unseen present fires. This is computationally intensive and requires thorough knowledge of past fires and the conditions surrounding them, which the team does not have. Additionally, the presence of methane and other emissions can be determined by processing images in the near-infrared spectrum (between visual and thermal infrared), which the data is available for. Processing these images for methane presence is quite involved and it is unlikely the project would have the time to include it (Dogniaux, 2023).

Land surface temperature (LST) data, obtained through satellite imagery, offers a valuable tool for detecting and monitoring landfill fires. Landfill fires emit significant amounts of heat, altering the thermal properties of the surrounding area. By analyzing LST data, anomalies indicative of elevated temperatures can be identified, serving as potential indicators of landfill fires. Thermal infrared sensors on satellites can capture these temperature variations, providing high-resolution imagery of the affected areas. Additionally, combining LST data with other image data, such as visible and near-infrared bands, allows for a comprehensive analysis of the fire's extent and impact on the surrounding environment. Temporal analysis of satellite imagery enables the tracking of fire dynamics and the evolution of the affected area over time. Thus, the integration of LST and image data offers a powerful remote sensing approach for early detection, monitoring, and management of landfill fires, facilitating timely responses to mitigate their environmental and public health consequences. This method has been used to monitor landfills in the past. In a 2020 case study, data from the Landsat-8 satellite and its predecessors was used to track subsurface smoldering in a Missouri landfill over the course of 17 years. The land surface temperature was calculated from the thermal infrared radiance as well as the vegetation index, itself calculated from visible red and near-infrared measurements (Nazari et al., 2020).

Translating infrared spectrum images into specific instances of fire on Earth's surface is done by measuring relative differences in brightness. However, making high-confidence identifications of fires requires image classification techniques and comprehensive analysis of surface conditions to prevent the detection of false positives. Creating such a classification algorithm is beyond the scope of this project, so the project team is relying on pre-processed data. For this, the best source is NASA's Fire Information for Resource Management System (FIRMS). FIRMS produces daily fire identification tracks from both MODIS and VIIRS data which can be easily loaded into ArcGIS for use in mapping. The algorithm FIRMS uses has been gradually tuned since VIIRS was first used in 2011. As of 2013, commission error, the rate of false positives, was reduced to less than 1.2 percent (Schroeder et. al., 2013). The appearance of the FIRMS webtool is shown in Figure 5. It also provided a sense of the 375-meter resolution.

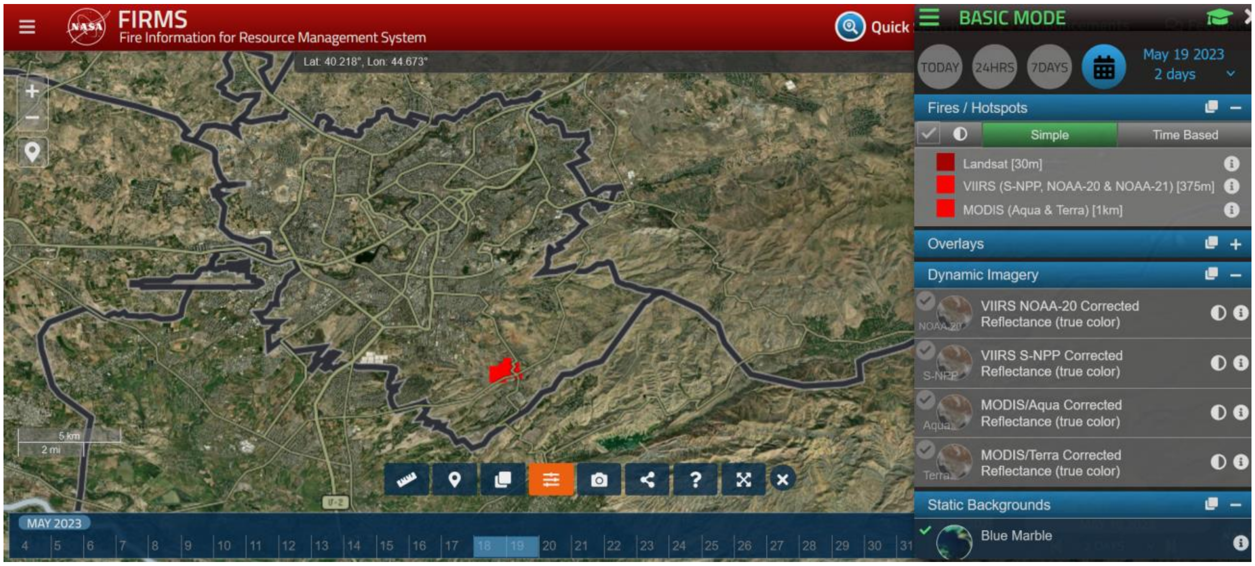

Figure 5: The May 2023 Nubarashen landfill surface fire identified by VIIRS and MODIS data as viewed in NASA's FIRMS web tool

4.2 Aggregate and Visualize Data Using ArcGIS

The second result of the project was the mapped visuals of the chosen data sources. The AUA Acopian Center for the Environment provided the project team with a shapefile detailing the location of landfills across Armenia, represented as polygons. This shapefile data was then integrated with fire data from NASA FIRMS spanning the past five years. By overlaying this fire data onto the landfill polygons, it was able to identify and mark the specific areas where fires intersect with landfills. With this technique completed, two visuals were created.

4.2.1 Five Year Aggregate Map

In addition to marking the intersections between landfills and fire incidents, the project team incorporated fire icons to represent the frequency and intensity of these occurrences visually. These icons indicate how often a landfill has experienced a fire and convey the Fire Radiative Power (FRP) associated with each fire. FRP measures the intensity of heat released during a fire. Darker shades on the icons represent higher FRP values, enabling a clear depiction of areas with more intense heat emission (Schroeder & Giglio, 2018) (Wooster et. al., 2003). By integrating these additional layers of information, a comprehensive assessment of the impacts of landfill fires was completed. Furthermore, the project team's analysis was enhanced by incorporating datasets featuring Armenian forests and settlements. This multidimensional approach allows for analysis of the potential effects of fire incidents on surrounding ecosystems, including forests and water bodies, as well as on nearby human settlements. The final map is a combination of the fire icons, landfills marked as polygons, water, forest, and human settlement data. The map shows which landfills have been on fire in the past five years with the fire icons and makes it easier to see which landfill fires affect nearby human settlements and are close to forest or water. As shown in Figure 6 there are fire icons on the map of different sizes and colors. The Nubarashen landfill stands out as the most fire-prone landfill, evidenced by its frequent incidents and high Fire Radiative Power (FRP). A large number of landfill fires, including the Nubarashen landfill, are close to Yerevan, which is marked yellow as a highly populated territory, and some are close to Lake Sevan, including one with a high FRP. A lot of other landfill fires are close to forests, marked green, signaling potential ecological threats.

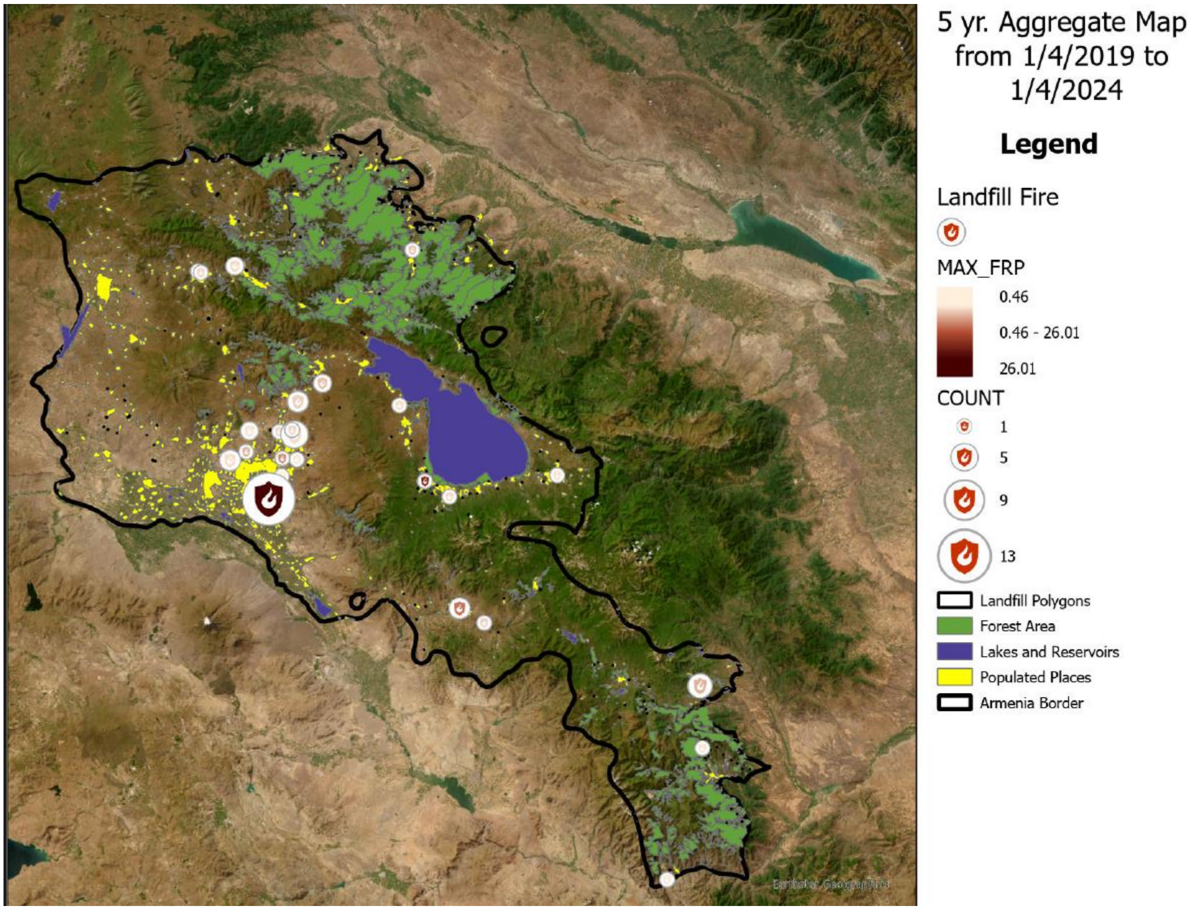

Figure 6: Five-Year Aggregate Map Screenshot.

This aggregated map determined the rankings of the landfills based on the number of times it has been on fire, the maximum FRP, and if it's close to communities or forests.

4.2.2 Time Series Video

The second visual created was a time series video. Data was collected from the past five years and presented in a video. Figure 7 shows one interval from the time series video: the summer months of 2021. A link to the entire video is in Appendix D.

Figure 7: Seasonal Time Series Screenshot.

Each step in the video shows the data from the three months that are selected, then it goes to the next step showing the next three months. There is also an indicator to show what season it is. This allows the user to easily understand the seasonality effect on landfill fires. This effect can be observed in that there are more fires present in the summer months compared to the winter months. This could aid decision-makers in choosing when to implement their monitoring and mitigation techniques during the summer when the most fires are present.

4.3 Landfill Fire Risk Rankings

This project aimed to identify the fires that both have the highest frequency of fire as well as pose the greatest risk to the surrounding communities. A ranking was established for every landfill that has caught on fire for the last five years, taking distance from surrounding communities, closeness to forests, fire frequency, and fire radiative power into account. As mentioned in the methods, the formula the team created was as follows: $R = C*(3 + S + F) + FRP$.

In the formula R is the risk score, C is the count of fires, S is a boolean value of one if the landfill is near a settlement and zero if it is not, F is a boolean value one if the landfill is near forest and zero if it is not, and FRP is the maximum fire radiative power. Professor Harutyunyan from the AUA Acopian Center for the Environment provided the forest and settlement data. The count of fires and maximum fire radiative power were derived from the NASA Firms data. Table 2 has the ten highest-scoring landfills in Armenia based on the created formula.

Table 2: Top Ten Ranking of Landfills

Rank	Location	Count of Fires	Max FRP	Close to Communities	Close to Forests	ArcGIS Map Coordinates (m)	Risk Score
1	Nubarashen	13	26	Yes	No	464,831.20E 4,445,889.2N	78
2	Goris	4	5	Yes	Yes	616,471.65E 4,372,684.5N	25
3	Dzoragyugh	1	18	Yes	No	517,631.13E 4,446,169.6N	23
4	Southeast of Yeghegnadzer	3	10	Yes	No	530,075.25E 4,400,517.8N	22
5	Small landfill in Kotyak Marz at intersection of H1 highway and Kotayk'i Jrants	5	1	Yes	No	470,741.52E 4,462,889.4N	21
6	Nor Nork District Dump (next to M15 highway)	2	6	Yes	Yes	464,831.20E 4,445,889.2N	16
7	Dump to right of Alapars and Charentsavan (south of Bjni)	3	3	Yes	No	471,997.02E 4,474,703.1N	15
8	Southeast corner of Aragatsotn Marz near Armavir Marz border close to Aragatsotn - Yerevan Border (leftmost dump)	3	2	Yes	No	447,659.17E 4,453,649.3N	14
9	Hrazdan Municipal Landfill	2	4	Yes	No	480,854.94E 4,481,331.4N	12
10	Getargel Dump, Kotayk Province	1	8	Yes	No	466,421.83E 4,454,372.6N	12

The landfill in Nubarashen poses the highest risk as it has caught on fire the most frequently, has the highest maximum fire radiative power, and is close to communities. For the rest of the rankings, the landfills were relatively close in scoring. Dzoragyugh was an outlier, as it is ranked high despite only having one fire in the last five years. It is ranked here because of the high max fire radiative power. The AUA Acopian Center for the Environment can use these three deliverables to make data-driven decisions in their future research.

Chapter 5: Conclusions

A time series and an aggregate map of the landfill fires in Armenia over the past five years were created as the final deliverable. From these maps, the team made the following observations of the state of landfill fires in Armenia. Firstly, within the limitations of the project, NASA FIRMS data provided the most feasible form of fire detection data. NASA FIRMS preprocesses the satellite data to detect fires, which makes it easy to detect which fires were in the range of the landfill boundaries on the project map without a preprocessing step. With both maps, it was possible to gain insights into the frequency and severity of landfill fires, as well as create a landfill fire assessment. It was discovered that there are more landfill fires in the summer and fall months than in the winter and spring months. By looking at the aggregate map, the team determined what landfills cause the most risk to the surrounding communities by associating fire radiative power (FRP) and frequency with settlement area and forest coverage data. This ranking can be used by the AUA Acopian Center for the Environment to prioritize which communities to focus their efforts on. Figure 8 shows the top five most at risk communities as points on a map.

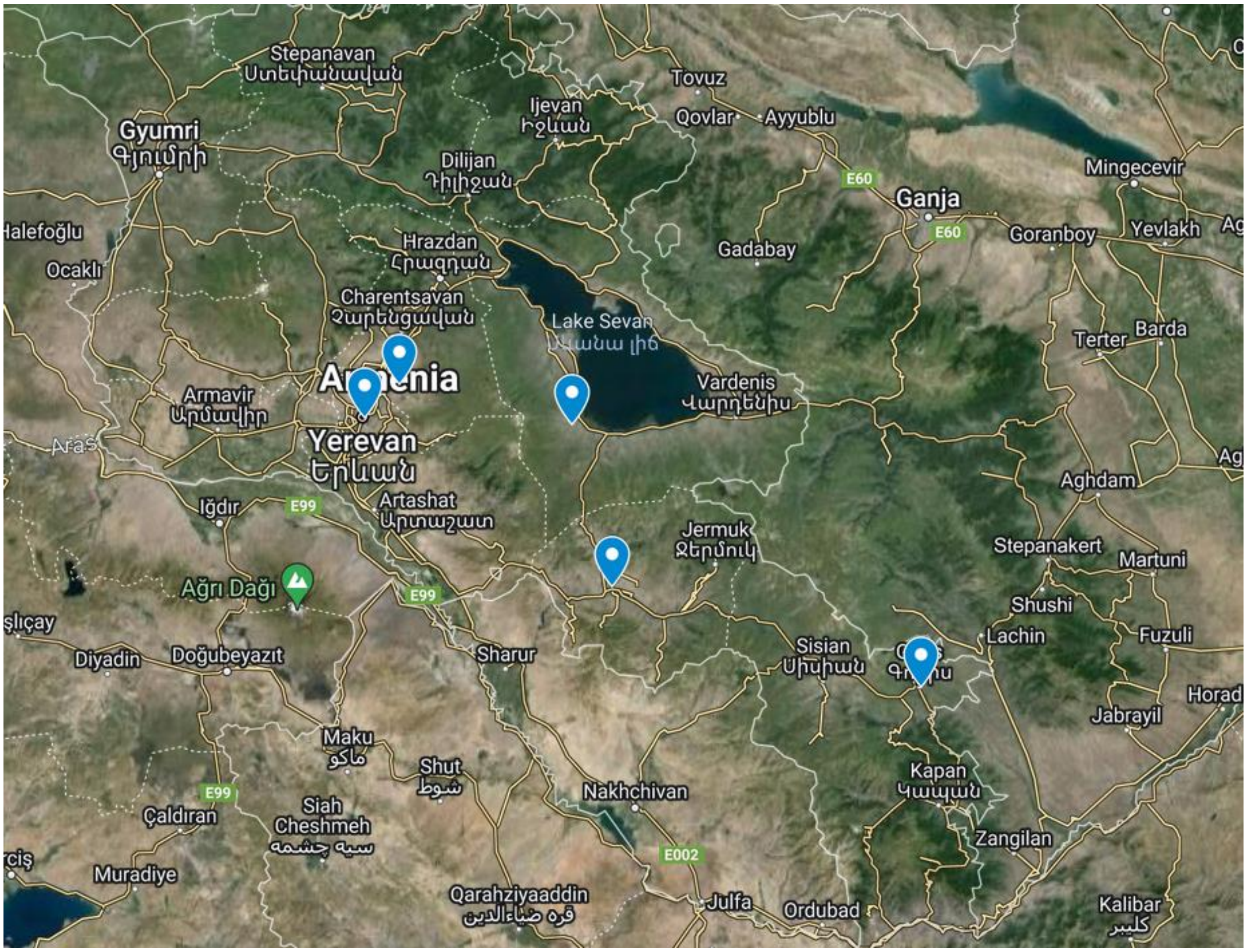

Figure 8: Top 5 communities affected by Landfill Fires in Armenia

The top five communities affected were Yerevan, Goris, Yeghegnadzer, Abovyan, and Dzoragyugh, as shown in Figure 8. These communities should be prioritized first in terms of implementing landfill fire mitigation techniques and studying the impact of the fires on the communities. Overall, this project provides valuable insights into the state of landfill fires in Armenia and a valuable foundation for future work in the area.

5.1 Limitations

Remotely sensed land surface temperature data has fundamental issues limiting how well it can spot fires. The most prominent issue with satellite observations is how the ground can be observed. Cloud coverage prevents the ground from being seen in images, as the clouds obscure the vision of the tools on the satellite. Cloud cover also varies seasonally, skewing results throughout the year. Summer is clear, while winter is cloudy about 50 percent of the time (Climate and Average Weather Year Round in Yerevan). Thus, colder months are biased to show fewer fires. Despite this, it is true that more fires do occur during the summer due to higher overall temperatures (Moqbel, 2009). One way to address this bias would be to delete some fires from the summer time; however, it was decided against this as having as many fires tracked as possible is important. Both spatial and temporal resolutions are limiting factors, the former especially. Many of the landfill polygons measure smaller than the 375 meter resolution of VIIRS, making detection more difficult for those sites. In a case study conducted along the Mediterranean coast of Turkey, Emre Çolak and Filiz Sunar found that 50 to 72 percent of forest fires detected by FIRMS were validated by the Turkish General Directory of Forestry in the Marmaris and Menderes regions, respectively (Çolak and Sunar, 2020b).

A further issue is the inability to determine the initial cause of each fire. A variety of causes were laid out in the background chapter, which can have completely different means of prevention. This information is impossible to precisely determine through remote sensing or even ground observations from a distance. Because of this, preventative measures cannot be taken without speculation into the cause of each ignition.

The map as it stands is lacking some useful supplementary information. This includes specifying not just the presence of settlements near landfills, but also the population density there. Adding newly acquired fire tracks past April 1, 2024, must be done manually, and does not automatically update. Although land surface temperature data is used, it cannot be viewed by itself.

Having access to this data is important for catching smaller fires missed by the FIRMS algorithm. Addressing these limitations is further discussed in section 5.2.8.

While the fire risk formula was based on a case study, the audience could value the attributes of the landfills differently. Additionally, the audience could desire to address the unit disagreement between the number of times the landfill has caught on fire and the maximum fire radiative power differently. For this reason, the formula can be manipulated based on the audience's preference in terms of what attributes they find most important when considering landfill fire risk.

5.2 Recommendations

Following the conclusion of the project, the following suggestions are put forth as potential avenues for research by both the AUA Acopian Center for the Environment and other research entities. These recommendations can be beneficial for the landfills and communities the project identified as having the greatest risk.

5.2.1 Deploy Air Quality Sensors

Landfill fires can have a significant impact on the surrounding air quality. Lowered air quality, especially an increase in particulate matter such as PM 2.5 and PM 10 PM, poses a risk to human health. Therefore, one suggestion to expand the project could be a citizen science project in which local citizens of areas impacted by landfill fires could buy or make an air quality sensor so that data on air quality in the regions surrounding the landfills could be monitored. To determine which communities this project should be expanded to, the landfill fire maps and rankings can be analyzed. One method for deploying air quality sensors would be to reach out to a project doing similar work already in Armenia. The Armenia Air Quality Index is a project hoping to spread air quality sensors throughout Armenia. They currently have 15 stations between 4 cities, with the majority in Yerevan. ("About," n.d.) As of April 2024 their sensors cost 35000 AMD ($90.51) for a pre-assembled kit and 30000 AMD ($77.58) for a kit the customer must assemble. There is also an option to buy the components without both casing and assembly. This is the most economical option the Armenia Air Quality Index offers; however, it requires that the customer can 3D print the casing or otherwise make their own themselves. Another potentially more economic option would be to create a sensor. This could be driven by a microcontroller board such as an Arduino ($17.50 as of April 2024) or a Raspberry Pi ($35.00 - $80 as of April 2024) with the addition of a wifi adaptor (Arduino specific) and air quality- specific sensors. With the adoption of this project, one could better quantify the impact of landfill fires on air quality in local communities.

5.2.2 Implement Citizen Science Fire Reporting

To improve the accuracy of the project's fire identification, a citizen science fire alerting program can be implemented. The project team has noted that it is possible to spot the smoke from landfill fires missed by NASA FIRMS on the ground in multiple spots around the city. A study done in Turkey in 2020 demonstrates the utility of using citizen science for wildfire reporting. This study showcased that instances of verified wildfires can be associated with tweets sent out by the local population (Çolak and Sunar, 2020b). A similar system for landfill fires, utilizing SMS or social media, could help in monitoring the landfill fires in Armenia. SMS-based fire alerting systems can be implemented in which citizens of communities near high-risk landfills can text a number whenever they see smoke from the nearby landfill. These can take the form of posters in well traveled locations such as the top of the Cascade Complex in Yerevan and popular hiking trails. This citizen reporting can provide both a method of ground truthing and potentially provide additional data points on top of the satellite data. Overall, if successfully implemented in the local communities, this can provide a valuable addition to the project without having much time or monetary cost.

5.2.3 Utilize Machine Learning and PlanetScope

While the project in its current iterations has a resolution of 375 meters using NASA FIRMS data, a project utilizing a higher resolution satellite should yield even better results. PlanetScope has the highest resolution of all the satellites considered for the project, with a visual resolution of 3 meters per pixel. The development of a landfill fire-specific image classification model could result in better accuracy of fire prediction utilizing PlanetScope data. The potential increase in accuracy using PlanetScope over NASA FIRMS would be dependent on the model development done by the researchers. One study, based in the Maldives, utilized PlanetScope data in conjunction with a convolutional neural network (CNN) model to detect plumes of smoke from dumpsite fires. The model involved using an "image classification and semantic segmentation model based on a pre-trained convolutional neural network to identify and locate plumes within images" (Scott et al., 2023). A CNN is a type of neural network primarily used for image recognition and processing. The CNN can be trained to detect whether a fire is present in the image or not. It uses the semantic segmentation technique to delineate the precise boundaries of the identified smoke plume. The image classification model uses the identified smoke plume, or lack thereof, to classify if a fire is present or not in the image. A similar project could potentially be implemented using Planetscope data for the landfills in Armenia. Using deep learning tools such as TensorFlow or Pytorch (Scott et al., 2023) it could be possible to train a neural network and use it for image classification and semantic segmentation (separating smoke plumes from background in this case). This could lead to greater accuracy in fire detection within the project maps. It is recommended that PlanetScope data is first collected and analyzed on specific landfills. This would allow the developers to have a narrower scope and ensure that their model is working. Nubarshen would be the best landfill to first focus on as it had the highest fire risk score based on the formula. Once a model has been developed, it would be possible to collect data on other high ranked landfills and apply the model to these landfills. Ultimately, this technique would be applied to all landfills across the country.

5.2.4 Develop Health Studies

COPD, or chronic obstructive pulmonary disease, is caused by prolonged exposure to small airborne particles. The principal causes of COPD are smoking, air pollution, and occupational exposure to noxious gasses and particles (Vinnikov et al., 2019). Landfill fires contribute to air pollution in Armenia. In 2019, a study was conducted on how lifetime occupational history contributed to COPD among 1,500 adults in Almaty, Kazakhstan. Information was collected on lifetime occupational history, cigarette smoking status and frequency, and their proximity to major roads (Vinnikov et al., 2019). Participants were also invited to take a spirometry test, which measures lung function, after the survey. This data was then used to determine the association between occupational hazards and COPD in Almaty, Kazakhstan (Vinnikov et al., 2019). A similar study is recommended to be conducted in the communities near landfills that the project rated as having a high risk. Questions on lifestyle and occupation should be associated with landfill proximity to discern the impact of landfill fires, rather than other correlating factors such as smoking, have on their surrounding population. Moreover, the data collected from such a study, as well as the project deliverable and the results of the other recommendations listed above, could potentially be used to help facilitate and inform policy changes in municipal dumpsites in the future.

5.2.5 Monitor Forest Fires

The AUA Acopian Center for the Environment has shown an interest in monitoring forest fires through remote sensing, having recorded the land affected by a fire in the Khosrov Forest State Reserve (Schlaffer et al., 2018). NASA FIRMS was designed with forest fires in mind, tracking them as if not more reliably than waste fires. Combined with existing forest coverage data, a map of forest fires using NASA FIRMS data is a natural extension of the existing project, taking minimal time to implement. This data could further be shared with relevant organizations such as the Hayantar State Non Commercial Organization (Armenia's Department of Forestry) and the Ministry of Environment's Eco-Patrol Service. Fire response in Armenia is currently handled by the Ministry of Emergency Situations (MES). As landfill fires are an issue for the country, firefighters can be made aware of the risks of their local landfills to better be able to respond to them. Further, the map, in conjunction with information on local fire services, can be used to determine risk areas that are currently underserved by MES.

5.2.6 Improve Landfill Infrastructure

In Armenia, at best, landfills are monitored dumps with no sorting of the mixed waste dumped into them. Unlike landfills developed to meet best practices, they do not have covers, a base layer between the dumpsite and the soil beneath it, or leachate collection or gas collection trenches, as shown in Figure 9 (Guzzone, n.d).

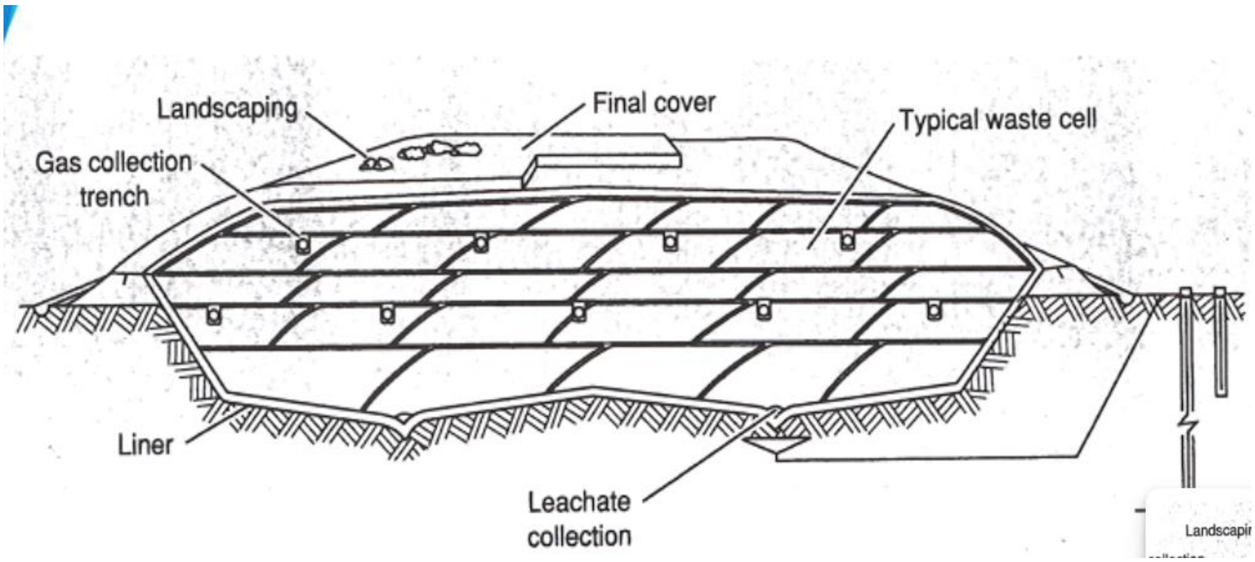

Figure 9: Diagram of Landfill Following Best Practices (Guzzone, n.d.)

All of the features shown in Figure 9 above, when implemented, lead to safer and better managed landfills that positively affect the health of the human population around them by reducing leachate runoff and fire risk. It is therefore recommended that Armenia follow and implement proper waste management techniques for all new landfills to be built. For existing dumpsites, especially the top 10 identified in fire risk rankings above, several steps can be taken to improve their safety. A dumpsite assessment (see Appendix C) should first be conducted to evaluate the current conditions of the dump, including its current slope, proximity to important waterways and cities, and current leachate contamination and gas emissions (Programme, U. N. E. & Sri Lanka M of E, 2021).

From the assessment in Appendix C, it can be determined whether it is best to eventually work towards the safe closure of the dump or to rehabilitate the dump in question. If dumpsite rehabilitation is not a viable possibility (total risk assessment score is above 600) or there are no plans for expansion of the landfill, it is recommended to securely close the dump and halt landfilling in the area (Programme, U. N. E. & Sri Lanka M of E, 2021). Otherwise, it is possible to implement a several stage plan to rehabilitate the dump. The first phase of either dumpsite rehabilitation or safe closure is to ensure the stability of the dumpsite (prevent slope failure and collapse) and to help minimize the future negative impacts of the dumpsite (environmental impacts, odor, disease spread, etc.) (Programme, U. N. E. & Sri Lanka M of E, 2021). The second phase of rehabilitating a landfill includes enabling landfill gasses to be safely emitted, preventing fires and explosions, collecting and safely disposing of leachate, and implementing appropriate landfill management techniques such as applying sufficient soil coverage to the landfill and final soil coverage on closed slopes (Programme, U. N. E. & Sri Lanka M of E, 2021). In Armenia, it is recommended that all dumpsites in the country be shaped and restructured to ensure landfill stability, and soil cover with vegetation, which helps prevent erosion, be implemented on all areas of the landfill in which there is no longer any dumping. It is recommended, if possible, for the installation of gas vents in the landfill to reduce fire risk. Moreover, leachate collection pipes should be installed in these landfills and drains be implemented around the landfill to help ensure stormwater runoff away from the dumpsite. With these implementations, it is possible to turn an uncontrolled dumpsite into a more sustainable and regulated one. With the guidance of this project team's fire risk map and the dump assessment guidelines, it is recommended that the country of Armenia work to close or rehabilitate the landfills that pose the greatest fire risk to the local communities to safeguard the health of its citizens.

5.2.7 Mapping Landfill Leachates

The major potential environmental impacts related to landfill leachate are pollution of groundwater and surface water. The dumpsite is composed of various kinds of waste that are being degraded by microbial activities together with various chemicals, metals, and other constituents of the dump. The waste becomes a source of water contamination when it finds its way to the water body through leachate migration. Leachates may also mix with the surrounding environment and bodies of water by rainfall flow. Groundwater pollution from dumpsite leachate can result from various pollutants, including heavy metals, nitrogen compounds, chlorinated hydrocarbons, phenols, cyanides, and bacteria. Electronic waste disposed of in dumpsites contributes to groundwater pollution by releasing toxins that seep into the groundwater. These electronic wastes contain heavy metals, and their presence in water bodies can impact both terrestrial and aquatic animals, ultimately affecting human health, particularly for those who use that water as drinking water. (Daniel et al., 2021) The selection of appropriate technology for treating landfill leachate primarily depends on several factors related to the leachate itself, such as its chemical oxygen demand (COD), landfill age, and the ratio of biochemical oxygen demand to COD (BOD/COD), as well as the desired removal efficiencies for COD, heavy metals, and NH4+-N concentrations in the effluent. Additionally, considerations include the flexibility of the treatment plant, overall effectiveness, operational costs, reliability, and installation requirements. Regarding removal efficiency, it has been observed that individual biological or physical-chemical techniques are often insufficient. Optimal removal of refractory organic compounds from stabilized leachate can be achieved through a combination of two or more physical-chemical treatments. On the other hand, effective removal of NH4+-N and COD typically requires a combination of biological and physical-chemical treatments (Nath & Debnath, 2022).

Considering the significant environmental impacts outlined above, creating a map of leachates is not only beneficial but also essential for effective environmental management and protection. By visually representing the distribution of landfill leachates and their potential pathways of migration into groundwater and surface water bodies, such a map can serve as a valuable tool for identifying areas at high risk of contamination. To create a map depicting landfill leachates in Armenia, data on landfills and water must be integrated into a GIS platform. By layering the data within ArcGIS, spatial relationships between landfill locations and nearby water bodies can be visualized, illustrating the spatial distribution of leachate contamination and its proximity to water sources. This would provide insights into potential pathways of leachate migration.

5.2.8 Implement Improvements to Map

To better monitor landfill fires and the fires that are most impactful to communities, improvements to the map should be implemented. The first improvement is considering adding three new layers of data. One layer is population density in the country. The map currently visualizes the settled areas in Armenia. The data the map currently uses provides information in regards to the proximity of landfill fires to settled areas; however, this data values all settlements as equal. If population density data were implemented, more information about landfill fires proximity to humans would be able to be gathered. Landfill fires near more densely populated areas could be prioritized first to monitor or reform, as these landfills have an impact on most humans. Another layer that could be added to the map is the slope of the ground in the landfill. As mentioned in the case study identifying and ranking forest fires in Turkey, the slope of the ground where the fire is present affects the rate at which it spreads. A steeper slope spreads fires faster as the slope strengthens the wind (Emre Çolak, 2020). By adding a slope layer to the map, one could determine the steepest landfills. This is significant, as if the landfill is steep, the fires in this landfill would spread much faster to flatter landfills, creating larger fires and emitting more pollutants into the air. The final layer that should be implemented would be air quality. While there is a lack of air quality data in Armenia, if the recommendation of deploying air quality sensors in the highly ranked communities were completed, a data source for air quality data would be available. This data could be layered onto the map to see where the air quality is the worst near the landfills. The worse the air quality is in the communities, the higher the urgency should be to reform the landfill and implement best practices. The three attributes of population density, slope of the landfill, and air quality would be implemented in our ranking formula for which landfills and communities to monitor and reform first.

There are also three technical improvements that should be implemented in the map. Using ArcGIS, one could determine the location of fire stations in Armenia. This would aid in the development of fire response infrastructure, while also providing information about where the current fire stations are in relation to landfills. Having fire stations have easy access to landfills would allow for quick responses to fires and limit the damage the fires cause. The next technical improvement would be making the data real time. This would be challenging as the data from NASA FIRMS is gathered by requesting it from their website, gets cleaned to delete duplicates, and many ArcGIS functions are applied to create the final visual. However, if the map was able to be real time, the AUA Acopian Center for the Environment would be able to see which landfills are on fire that day, and the deliverables of this project would not become outdated. To achieve real time data, they would have to automate the data cleaning. This should be done using python scripts to join the data sets from different satellites together and delete duplicate fires. This would also be helpful even if real time data is not implemented into the map. When the cleaning process is automated, all the AUA Acopian Center would have to do is request the data and follow the procedure to update the map.

These recommendations would provide an abundance of new information relevant to ranking the landfills as being most harmful and impactful to communities, while also keeping the map relevant.

5.3 Conclusion

The team is confident that even with the limitations of the current project, the implementation of some or all of the recommendations above, the maps created will be able to provide both a better understanding of the frequency and relevancy of landfill fires in Armenia and provide the basis for local community impact. Through providing better data on the seriousness and danger of their situation and by letting that data drive policy and infrastructure changes in the country of Armenia, the work produced in this project can have a real and sustained impact on monitoring and even potentially mitigating the landfill fires and its corresponding health and environmental effects in Armenia.

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Ինչպես են չափում օդի աղտոտվածությունը Հայաստանում, և ինչն է ազդում օդի որակի վրա—21.02.2023*, Sputnik Արմենիա*. (n.d.). Retrieved January 29, 2024, from https://armeniasputnik.am/20230221/inchpes-en-chapum-odi-aghtvotvatsutjuny-hajastanum-ev-inchn-e-azdum-odi-voraki-vra-55626315.html

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Appendix A: Base Armenian Landfill Map

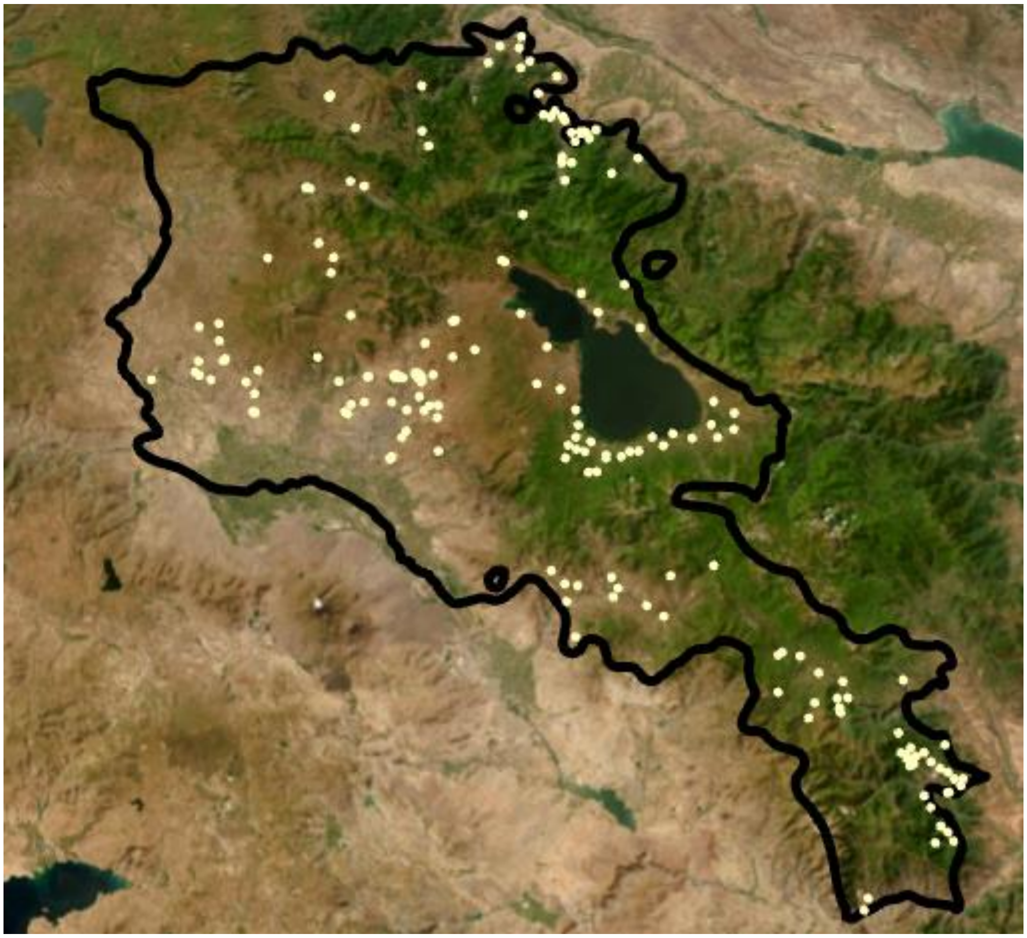

Figure A1: Map of Armenia with all the landfills the AUA Acopian Center for the Environment mapped and a manually drawn polygon by the project team around Nubarashen.

Appendix B: Map Procedures

To obtain the fire location data, one must make a request on NASA FIRMS for the shape files of SOUMI and J1 VIIRS data for the country and time frame desired (for this project it was Armenia and the last five years). From here the data can be loaded into ArcGIS. To create one data set, combine the two layers into one. Once this is done, clean the data to eliminate duplicate observations of fires. A duplicate for this project was deemed to be an observation with the same date, time, longitude, and latitude. There were no cases of observations being made within a day of each other in the same location; however, if this did happen it would be considered a duplicate and should be deleted. Once the cleaned data set has been obtained, the map should have all the landfills in Armenia and all the fires from the last 5 years. From here perform a spatial join with the landfills being the target and the fires being the join features. Make sure that the join operation is one to many and keep all target features is unchecked. The match option should be within a distance and the value is 375 to account for the location error in satellites data. Now a layer of polygons that represent fires in a landfill is created. From here to convert the polygon layer into points follow the “Find the centroid of polygons using Calculate Geometry in ArcGIS Pro” tutorial from ESRI. With the point layer created the time series video and aggregate map can be created. To create the time series, right click the layer in the contents pane and click properties. Here go to the time tab and click filter layer content based on attribute values and hit apply. Now the time attribute filters the data and the user can play around to make the video as they wish in the animation tab. To create the aggregate map search for the aggregate points tool. The point layer should be the layer of all the fires in the landfills that are not filtered by time. The polygon layer would be the landfills. The summary fields can be whatever attribute that should be aggregated, in this project it was count of landfill ID and maximum of the FRP. This outputs a polygon layer so the same tutorial must be found to make it into a point layer. Once it is a point layer, the symbology of the layer can be used to decide how the aggregated data is presented on the visual. This project used size to represent frequency and color for maximum fire radiative power. To export the map one must make a layout and then click the share tab.

Appendix C: UN Landfill Assessment Attribute Table

Table C1: List of attributes recommended by the UN when deciding whether a dumpsite can be rehabilitated or closed. (Programme, U. N. E. & Sri Lanka M of E, 2021)

No.	Attribute	Attribute Weightage	Sensitivity Index			
			0.0–0.25	0.25–0.5	0.5–0.75	0.75–1.0
	I - Site specific criteria					
1	Distance from nearest water supply source (m)	69	> 5000	2500–5000	1000–2500	< 1000
2	Depth of filling of waste (m)	64	< 3	3–10	10–20	> 20
3	Area of the dumpsite (Ha)	61	< 5	5–10	10–20	> 20
4	Groundwater depth (m)	54	> 20	10–20	3–10	< 3
5	Permeability of soil (1 x 10^{-6} cm/s)	54	< 0.1	1–0.1	1–10	> 10
6	Groundwater quality	50	Not a concern	Potable	Potable if no alternative	Non-Potable
7	Distance to critical habitats such as wetlands and reserved forest (km)	46	> 25	10–25	5–10	< 5
8	Distance to the nearest airport (km)	46	> 20	10–20	5–10	< 5
9	Distance from surface water body (m)	41	> 8000	1500–8000	500–1500	< 500
10	Type of underlying soil (% clay)	41	> 50	30–50	15–30	0–15
11	Life of the site for future use (years)	36	< 5	5–10	10–20	> 20
12	Type of waste (MSW/HW)	30	100% MSW	75% MSW + 25% HW	50% MSW + 50% HW	> 50% HW
13	Total quantity of waste at site (t)	30	< 104	104–105	105–106	> 106
14	Quantity of wastes disposed (t/day)	24	< 250	250–500	500–1000	> 1000
15	Distance to the nearest village in the predominant wind (m)	21	> 1000	600–1000	300–600	< 300
16	Flood risk (flood period in years)	16	> 100	30–100	10–30	< 10
17	Annual rainfall at site (cm/y)	11	< 25	25–125	125–250	> 250
18	Distance from the city (km)	7	> 20	10–20	5–10	< 5

No.	Attribute	Attribute Weightage	Sensitivity Index			
19	Public acceptance	7	No Public concerns	Accepts Dump Rehabilitation	Accepts Dump Closure	Accepts Dump Closure and Remediation
20	Ambient air quality - CH_4 (%)	3	< 0.01	0.05–0.01	0.05–0.1	> 0.1
	II - Related to characteristics of waste at dumpsite					
21	Hazardous contents in waste (%)	71	< 10	10–20	20–30	> 30
22	Biodegradable fraction of waste at site (%)	66	< 10	10–30	30–60	60–100
23	Age of filling (years)	58	> 30	20–30	10–20	< 10
24	Moisture of waste at site (%)	26	< 10	10–20	20–40	> 40
	III - Related to leachate quality					
25	BOD of leachate (mg/L)	36	< 30	30–60	60–100	> 100
26	COD of leachate (mg/L)	19	< 250	250–350	350–500	> 500
27	TDS of leachate (mg/L)	13	< 2100	2100–3000	3000–4000	> 4000
	Cumulative attribute weightage	1000				

Appendix D: Five Year Seasonal Time Series Video Link

Youtube link: https://youtu.be/afJ7jyq3_LU?si=i0zp_r01zFTnLvww