EXPLORING THE POTENTIAL IMPACTS OF WASTE DISPOSAL SITES ON OCEAN ECOSYSTEM CONTAMINATION IN NEWFOUNDLAND: A GEOSPATIAL ANALYSIS AND PUBLIC PERCEPTION STUDY

by

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Abstract

This study endeavors to identify historical (closed) and currently operational landfill/waste disposal sites in Newfoundland that might be environmentally sensitive. The primary focus is to understand the potential impacts of these sites on neighboring water bodies and ocean ecosystems. Through the utilization of geospatial analysis, this study examines how waste disposal sites in Newfoundland could possibly contaminate water bodies and ocean ecosystems. Additionally, the study assesses public perceptions concerning the ecological and human health implications of waste disposal sites on the surrounding environment.

Employing a geographic information system and the multiple criteria decision-making model, this study assesses the influence of waste disposal sites on nearby water bodies and the ocean. By implementing an analytical hierarchical process, a variety of environmental factors such as soil composition, topography, groundwater vulnerability index, hydrogeology, land use, and land cover are systematically ranked to determine the environmental vulnerability of each waste disposal site. The outcome is presented through a vulnerability assessment map, which categorizes dumpsites based on their level of vulnerability—high, moderate, or low.

Recognizing the potential of public engagement to bolster social justice and draw attention to pertinent issues, this study integrates a diverse group of stakeholders such as community members, town councilors, mayors, landfill managers, public health experts, environmental scientists and engineers, provincial government officials, recyclers, and waste disposal service providers. Interviews were conducted with these stakeholders to gain their perspectives on the potential impacts of waste disposal sites on ocean contamination in Newfoundland. From the transcribed interview data, multiple thematic areas pertaining to present waste management practices and the environmental and health ramifications of waste disposal sites were comprehensively identified.

General Summary

In both developed and developing nations, landfilling remains a primary waste disposal method. The location of a landfill has a significant impact on the neighboring biophysical environment and ecology. This study's objective is to evaluate the potential impacts of waste disposal sites on nearby water bodies and ocean ecosystems. By incorporating environmental variables such as slope, soil drainage, and hydrogeological data into the GIS interface, an analytical hierarchical weighted model and multi-criteria decision-making method were used to analyze the environmental vulnerability of both closed and operational waste disposal sites. Examining these environmental factors in the context of landfill contamination provides a comprehensive understanding of how contaminants can move through the environment and impact ecosystems, water resources, and human health. This knowledge is crucial for designing effective waste management strategies and minimizing the negative effects of landfill contamination. This study utilizes geospatial technology to classify waste disposal sites into categories of high, moderate, and low vulnerability.

Public participation in environmental and social issues can increase social equity, identify problems, and guarantee that the public's concerns and aspirations are consistently acknowledged and considered by decision-makers. This study comprehends and assesses the prevalent perceptions, ideas, and opinions of community members, environmental scientists and engineers, public health officials, landfill managers, recyclers, and waste disposal service providers regarding the potential environmental and health impacts of landfills and waste disposal sites on water bodies and the ocean ecosystem.

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Preface

This thesis has been written as a series of manuscripts in Chapter 2 and 3. Some repetition of introductory and methodological material is unavoidable.

Chapter 2 Hazarika, R., Saxena, P., Sarkar A., Zhang, B.H., Achari, G. Geospatial analysis of potential impacts of waste disposal sites in the water bodies and ocean ecosystem of Newfoundland (Canada)

Chapter 3 Hazarika, R., Sarkar A., Zhang, B.H., Achari, G. A public perception study on the possible environmental and health impacts of waste disposal sites on the water bodies and ocean ecosystems of Newfoundland.

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List of Abbreviations

GIS Geographic Information System

AHP Analytical Hierarchical Process

MCDM Multi Criteria Decision Making

NL Newfoundland and Labrador

PCB Polychlorinated biphenyls

EPRA Electronic Products Recycling Association

PBDE Polybrominated Diphenyl Ethers

Chapter 1: Introduction

1.1.Background and Rationale

Ocean contamination stands as one of the most critical global challenges today, exerting a direct and profound impact on ecosystem health. A significant amount of waste and other types of contaminants are dumped into the ocean on a regular basis. The majority of ocean pollutants arise from anthropogenic activity on land, and these activities are concentrated mostly along the coastlines (Laura, 2021).

Ocean contamination not only has a negative impact on the health of marine ecosystems but also on the health of humans as a result of the consumption of contaminated seafood. According to a study conducted by Pandey et al. (2012), populations dependent on the consumption of marine fish for their nutrient sustenance may be at risk due to the presence of persistent organic pollutants (POPs). Another study by Gagnon et al. (2004) stated that there is a sufficient concentration of inorganic arsenic and polychlorinated biphenyls (PCBs) in shellfish harvested on the north coast of the lower estuary of the St. Lawrence River to contribute to an increased risk of cancer.

The contamination of ocean ecosystems is caused by human activity such as industrial discharge, improper waste disposal, oil spills, agricultural runoff, plastic pollution, and overfishing coming from a variety of different sources, each of which contributes a diverse range of anthropogenic contaminants (industrial chemicals, heavy metals, pesticides, pharmaceuticals, plastics, and other materials) that have harmful effects on ecosystems, wildlife, and human health. One of the potential causes of ocean contamination is the migration of leachate runoffs from landfill sites. Runoff from landfills is likely to be the primary source of POPs in marine food webs, according to a recent study conducted by Trubridge (2016). According to the findings of another study by Przydatek et al. (2019), landfills used for the disposal of municipal solid waste have a negative impact on the quality of groundwater, affecting the taste, odor, and safety of groundwater used for drinking, irrigation, and other purposes.

In Newfoundland and Labrador, waste was previously sent to 240 disposal facilities that served 654 communities. Currently, there are only two regional disposal sites (Norris Arm in the central region and Robin Hood Bay in the eastern region), and the western region has chosen to send its waste to Norris Arm. Historically, landfills were often located in low-lying coastal locations. These landfills were not constructed with leachate management in mind. Closed and post-closure repurposing of such waste sites could pose a number of environmental problems if proper closure protocols are not followed (Victoria, 2022). This may lead to problems such as the release of hazardous and nonhazardous compounds, unpleasant odors, and gas into the nearby soil, water bodies and air. Since 2002, 72% of the older garbage disposal sites in the province have been closed. Nonetheless, due to their proximity to the coast, they could still constitute an environmental threat (Municipal Affairs and Environment, 2017).

Currently, there is a notable absence of comprehensive scientific investigations documenting the intricate routes through which toxic contaminants migrate from landfills to the marine ecosystem in Newfoundland, Canada. Consequently, it is imperative to conduct geospatial analyses that assess the susceptibility of both closed (unlined) and operational landfills in Newfoundland affecting nearby water bodies and the ocean ecosystem.

Furthermore, it is crucial to gain insights into public perceptions regarding the efficiency of the existing solid waste management system. This understanding is pivotal for shedding light on the environmental consequences of landfills on ocean contamination and the associated health risks. It also aids in identifying any concerning aspects related to prevention efforts. Ultimately, these efforts aim to enhance decision-making processes and the overall control and management of waste operations in Newfoundland. Ocean contamination poses a significant risk to the marine ecology, and because it eventually makes its way up the food chain to humans, it also poses a risk to human health. A study by Babichuk et al. (2018) suggests that there may be a potential health risk in the local population of Newfoundland owing to exposure to polybrominated diphenyl ethers through the consumption of local fish such as Atlantic cod and turbot.

According to a study by Naveen et al. (2018), leachate from municipal solid waste dumps showed the potential to seep into groundwater aquifers, eventually making its way into the nearby river system and harming the environment in its immediate vicinity. According to a study published by Ngo (2022), the majority of debris observed in the ocean is caused by trash that is washed into the water from landfills and urban runoffs. A recent study (Nicholls et al., 2021) demonstrates that there is a widespread scientific consensus on the uncontrolled release of solid wastes to the coast through erosion, which is harming both the marine environment and human life. These solid wastes may be altered by leaching and degradation within a landfill, and the risk associated with the release of solid waste is a chronic and long-term problem. Leaching and degradation are two processes that occur naturally.

Over the course of many centuries, the disposal of waste has predominantly involved the unfortunate practice of releasing garbage into rivers and estuaries, ultimately finding its way into the vast expanse of the ocean (Hoornweg, D et al., 2013). In this context, the focus of the study was to comprehensively explore the potential impacts of Newfoundland's landfills on the ocean ecosystems. Given the lack of prior investigation into this specific topic, the study emerged as a necessary endeavor to shed light on the potential environmental repercussions of waste disposal sites.

According to the findings of a research study conducted by Babichuk et al. (2015), the St. Lawrence River and Great Lakes are both significantly contaminated with POPs. Because of its location in the

Gulf of Saint Lawrence, Newfoundland is susceptible to the drainage systems of both the Great Lakes and the Saint Lawrence River. In a study carried out by Li et al. (2012) leachate samples taken from landfills all around Canada were analysed for the presence of POPs. It is likely that leachate from landfills follows the slope of the land to reach adjacent water bodies and streams and then travels farther by surface runoff to larger bodies of water such as lakes, rivers, or oceans.

Therefore, a geospatial risk assessment and evaluation study is essential to estimate the risk of landfill leachate runoff into the oceans. Moreover, since there has been no evidential study on the local level of ocean contamination in Newfoundland, this study would be beneficial for policymakers to do an assessment of landfills/waste disposal sites as a local potential source of contamination in the ocean coastal ecosystem. Environmental concerns are best managed with the participation of all interested individuals and concerned authorities at the appropriate level. A cost-effective technique is to raise awareness of household waste management among the general public to achieve positive social, economic, and environmental effects. Modern, efficient waste management promotes resource conservation by lowering consumerism, boosting social justice, and improving economic efficiency (Zyadin et al., 2020).

Our knowledge is limited when it comes to considering landfills as a potential source of contamination in marine environments. A lack of awareness may be related to this knowledge gap. Therefore, it is imperative to carry out a qualitative analysis based on how the general public and major stakeholders such as waste management officials, health officials, and environmental scientists perceive the effects of landfills/waste disposal sites on the possible contamination of ocean ecosystems and the potential health risks associated with consuming contaminated local seafood.

1.2. Study Objectives

The first objective of this study was an assessment of the waste disposal sites and their possible effects on nearby water bodies and the ocean ecosystems of Newfoundland using geospatial technology.

The second objective of this study was to understand and assess the general beliefs, notions, and viewpoints of the public and various stakeholders on the potential adverse effects of waste disposal facilities on water bodies and the ocean ecosystem in Newfoundland, the environment, and human health by delving into the complicated dynamics that occur at the interface between waste management and the marine environment.

1.3. Outline of Thesis

Chapter 2 assesses the vulnerability of the waste disposal sites to the local waterbodies and ocean ecosystems of Newfoundland, Canada through geospatial analysis. Chapter 3 focuses on the public perception of environmental impacts of waste disposal sites and their associated health risks due to the consumption of contaminated local seafood.

Chapter 2 and chapter 3 are manuscripts written that include their own introduction, methods, results, discussion and conclusion sections.

Chapter 4 addresses the general discussion and conclusion, limitations and scope for future work in this research study.

Chapter 2:
Geospatial analysis of any potential impacts of waste disposal sites in the water bodies and ocean ecosystem of Newfoundland (Canada)

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Abstract

The migration of leachate runoffs from landfill sites is considered a potential reason for ocean contamination resulting in adverse impacts on marine ecosystems and human health as a result of the consumption of contaminated seafood. The intent of this study is to identify the potentially vulnerable historic (closed) and operational landfill/waste disposal sites located in Newfoundland (Canada) and their impact on the nearby waterbodies and ocean ecosystem by analyzing a variety of environmental factors (topography, hydrogeology, soil, land use - land cover, and groundwater vulnerability data). This paper presents a geographic information system (GIS)-based analysis and analytical hierarchical process/multiple criteria decision-making (MCDM) method to assess waste disposal facilities' potential impact on nearby water bodies and the ocean. To examine the vulnerability factor of a waste disposal site in the environment, a hierarchical weighted model was created by taking into consideration environmental variables such as slope, land use/cover, hydrogeology, and soil drainage/texture. The relative importance of environmental factors that establish the vulnerability of waste disposal sites was determined using an analytical hierarchical process. In GIS, a comparison matrix was created to incorporate various criteria with environmental factors using the weighted sum overlay method. The waste disposal sites with high, moderate, and low risks of impacting ocean ecosystems were shown on a weighted vulnerability map. No previous studies have examined the impact of waste-disposal facilities on Newfoundland's ocean ecosystems.

Keywords: Remote Sensing; Geographic information system; Landfill; Multi-criteria decision-making; Analytical Hierarchical Process, Weighted sum overlay; Vulnerability assessment.

2.1. Introduction

Newfoundland and Labrador (NL), an eastern province of Canada renowned for its rugged landscapes and pristine coastal regions, faces a growing concern in the potential environmental impacts of waste on its water bodies and the delicate ocean ecosystems that surround this picturesque province (Max et al., 2020). NL produces 400,000 tons of waste annually (Department of Environment, 2019). Previously in the province, waste was distributed to 240 waste disposal facilities that served approximately 654 communities. By the year 2017, the majority of these unlined old waste disposal sites had been closed down in a phased manner, accounting for 72% of the total waste disposal sites (Municipal Affairs and Environment, 2017). However, old waste disposal could still be a threat to the environment as these dump sites did not have leachate control planned into their construction when they were first developed. Historically, landfills were frequently constructed in low-lying coastal areas, sometimes with the purpose of diluting and gradually dispersing contaminants within intertidal sediments. Due to alterations in the global climate and sea level rise, a new challenge has emerged in the form of coastal erosion and pollution from these historic coastal dump sites (Irfan et al., 2018; Brand et al., 2017). Closed and post-closure repurposing of waste sites could pose a number of environmental problems if the required closure protocols are not followed or the properly engineered containment systems are not implemented (Victoria, 2022). This may result in problems such as the release of hazardous substances, unpleasant smells, and gas up to thirty years after the site is closed (Government of Canada, 2002). If municipal solid waste (MSW) is not properly managed, it could result in environmental hazards that threaten both the ecosystem and human health (Vinti et al., 2021). Hence, monitoring both inactive and active waste disposal sites, including effective leachate management, groundwater monitoring, and cover maintenance, is essential (Capaccioni et al., 2011). The responsible management of waste, particularly the legacy of closed sites and the ongoing operation of others, is a pivotal issue that requires thorough investigation. The rates of generation of MSW have dramatically increased throughout the world as a result of growing urbanization, expanding economies, and growing population (Sumathi, et al., 2008). The province also faces the challenge of managing waste generated by its growing population and industries. A lack of planning on both the macro and local levels, as well as a shift in consumer habits, have contributed to an exponential increase in municipal waste and the current environmental crisis despite advances in technology and the management of urban waste disposal (Jara-Samaniego et al., 2017). Landfills, waste disposal facilities, and their associated environmental impacts have become a significant concern for both local communities and ocean ecosystems. This analytical study is particularly vital due to the island of Newfoundland's unique geographical characteristics as there are currently no scientific studies that provide a detailed account of the pathways of toxic contaminants from landfills to the marine ecosystem in Newfoundland.

The location of a landfill has impacts on its surrounding ecosystem and the biophysical environment (Kaiser, 2021). As the demand for waste management solutions continues to rise, understanding the implications of these sites on the province's natural environment has become increasingly critical. Geospatial technology plays a pivotal role in studying landfill contamination by providing tools for site assessment, monitoring, prediction, and response. It enhances our ability to understand and mitigate the environmental and health risks associated with landfills, ultimately contributing to more sustainable waste management practices (Mati et al., 2022). Hence, to address this issue, a geospatial analysis has been undertaken to comprehensively assess the potential effects of waste disposal sites on the aquatic ecosystems of Newfoundland. The overarching goal of this analysis is to provide a comprehensive understanding of the spatial relationship between waste disposal sites and nearby water bodies, with a specific focus on potential impacts on the ocean ecosystem. The selection of dump sites using various mathematical models has been the subject of numerous studies over the past few decades (Singh, 2019). Some relevant studies on municipal landfill siting and solid waste management have integrated GIS and MCDM in various ways, including the analytic hierarchy process (AHP) (Kamdar et al., 2019). MCDM is a well-known and widely utilized technique for the vulnerability assessment or site suitability analysis of landfill sites (Karimi et al., 2019).

By integrating geospatial technology, such as GIS, and employing multiple criteria decision-making methods like AHP, this study aims to identify areas of concern, assess vulnerabilities, and inform decision-making and policy development. Important variables for waste disposal site selection or for the vulnerability assessment of dumpsites include distance from roadways and surface water bodies, restricted or protected areas, subsurface water, land use and cover, soil types, land elevation, and hydrogeological parameters (Kebede et al., 2021). This investigation delves into various environmental variables, including topography, soil characteristics, land use and land cover, hydrogeology, and the groundwater vulnerability index to create a vulnerability assessment map of waste disposal site locations in the province, which are ranked as high, moderate and low accordingly. The insights gained from this analysis will help policymakers, environmental agencies, and local communities make informed choices regarding waste disposal practices, ensuring the preservation of Newfoundland's unique and fragile marine ecosystems for generations to come.

2.2. Materials and Methods

2.2.1. Study Area

The island of Newfoundland is roughly triangular in shape with an area (excluding associated islands) of 108,860 square kms (Figure 1). The predicted population in 2023 is 477,787. Newfoundland generally has cold but not severe winters and warm to cool summers due to its close proximity to water. Given the proximity to the ocean and the location of the majority of historical/old waste disposal sites along the coast of the province, it is vital to conduct a vulnerability assessment study of waste disposal sites that might release toxic contaminants into nearby water bodies and the ocean ecosystems.

2.2.2. Data Variables

This study used primary data sets (Figure 2) from various sources as input parameters for vulnerability assessment mapping. The Google Earth Engine was used to get a digital elevation model (DEM) of the study area with a 30-m spatial resolution https://earthengine.google.com/, while the satellite image was downloaded from the United States Geological Survey Earth Explorer site https://earthexplorer.usgs.gov/. Soil classification data were acquired from the Food and Agriculture Organization's database. Hydrogeological data were provided by the Geological Survey Division, Dept. of Industry, Energy and Technology, Government of Newfoundland and Labrador. Waste Management – Municipal and Provincial Affairs of Newfoundland has provided the geographic locational information on the waste disposal sites. Further, ArcGIS Pro Software was used to process them into individual data layers. Land use land cover data were derived from Landsat 8 satellite imagery.

2.2.3. Data preprocessing

The data were preprocessed to improve their functioning in GIS prior to the vulnerability analysis. Atmospheric correction and geometric correction of satellite images with location precision are necessary for land-use/land cover mapping (Lu et al., 2002). In this study, Landsat 8 satellite data were used to classify land use land cover of Newfoundland. Atmospheric path radiance in the Landsat 8 image was corrected using the dark object subtraction technique (De Keukelaere et al., 2018) prior to classifying the satellite data into different land use land cover classes using the supervised classification technique and accuracy assessment tool in ArcGIS software. The topography of Newfoundland has been studied using a DEM (Figure 3). The DEM was also used to derive the slope, aspect, flow accumulation, and stream order in the ArcGIS platform. The soil and hydrogeology data were generated in vector format (polygon feature). The ArcGIS platform was used to convert the vector data format to raster data (grid format). The vector to raster conversion was done so that all the layers could be incorporated into the GIS interface for the weighted sum overlay analysis. In preparation for further analysis, the groundwater vulnerability index data were exported from the Excel file format and imported into point shapefiles.

2.2.4. Methodology framework

Creating a methodological framework for integrating environmental variables like slope, topography, soil, and others into a GIS using the reclassification technique involves several steps. This framework (Figure 4) outlines the systematic approach to preprocessing and integrating these variables for geospatial analysis.

2.2.4.1. Analysis of Data Variables

The environmental data variables (Figure 5) utilized in this study are presented in this section to emphasize the significance of their functions in examining the potential impact of waste disposal sites in ocean ecosystems. The study defines reclassification schemes for each environmental variable. This involves grouping or reassigning values to create meaningful classes or categories.

2.2.4.1.1. Slope

To estimate the potential runoff from landfills and waste disposal sites in a certain distance and direction depending on the slope of an area, the slope's gradient[1] is one of the most crucial factors to consider (Othman et al., 2021). The slope is one of the most important factors in determining which waste disposal location is most susceptible to environmental impacts since water flows from higher to

1 Slope gradient, also known as the slope or gradient of a line, is a measure of the steepness of a slope or the rate of change of elevation over a given distance.

lower elevations along the gradient with the steepest gradient (Alavi et al., 2013). In this study, the ranking was assigned to the slope in increasing order, beginning with the category representing the steepest slope (83%) with the highest rank of 5 and ending with the category representing the lowest level (0–1%) with the lower rank of 1 (Figure 5(a)). The slope of the area under study is highly diverse, ranging from almost entirely flat to very steep.

*2.2.4.1.2. Aspect*Aspect defines the direction of the slope of the study area (Figure 5(b)). If the slope of a waste disposal site or landfill is sloping in the direction of an ocean shore, any inland water body, or a human settlement, then the likelihood of leachate discharge into the waterbody is assumed to be high. Similarly, the possibility of runoff into the water bodies could be reduced if the direction is away from the coast or any waterbody. Therefore, if the slope from a landfill/waste disposal site is towards the ocean shore, any inland water body, or a settlement area, it is assigned a rank of 5 (high/very high risk). Similarly, if the direction is away from the coast or any waterbody, it is assigned a weight of the lower rank of 1 (low/very low risk).

2.2.4.1.3. Flow accumulation

ArcGIS's spatial analyst tool was used to process a DEM to create a stream order and a flow accumulation map. According to Kenny & Matthews (2005), a flow accumulation raster (Figure 5(c)) computes the number of cells in the study region that will contribute to flow into each raster cell. It determines the size of the area over which water can build up over time due to precipitation such as rain and snow. In addition, it illustrates the area that contributes to a watershed and has a strong correlation with the watershed's surface runoff and its peak discharge. The flow direction method produces values in the following ranges: 1, 2, 4, 8, 16, 32, 64, and 128. The value for the flow direction will be 1 if the water flows in the direction indicated by the steepest slope or the one with the greatest height difference and 16 if it flows in the opposite direction. The highest ranking is given to the value 1 (steepest slope directional flow), which receives a ranking of 5, while the value 16 (gentle slope), which is the opposite direction, receives a ranking of 1.*2.2.4.1.4. Hydrogeology* The hydrogeology of the area (Figure 5(d) is one of the most significant determining factors (Longe & Enekwechi, 2007) that must be considered when assessing the potential threats posed by waste disposal sites. Hydrogeological data are included to get information about groundwater flow directions in soil and rocks (generally in aquifers). Three types of groundwater sources have been identified through hydrogeological analysis: (I) Groundwater that is held above bedrock in unconsolidated surficial deposits and is normally accessed by shallow wells is an example of an overburden source. (II) Bedrock with secondary permeability: rocks in which significant water movement occurs primarily through fracture systems associated with folding or faulting or in solution channels along fractures and bedding planes. (III) Bedrock with primary permeability: typically, sedimentary rock formations where the rock mass is generally permeable via pores between grains (Hydrogeology of Eastern Newfoundland, 2013). The high yield sandstone/sedimentary rocks were given a higher internal weightage of 5 since they were considered to have a high percolation rate based on the hydro stratigraphic unit and lithology. Granite or volcanic strata have been given a lower ranking value of 1 due to the minimal risk factor.

2.2.4.1.5. Stream order

The stream order map (Figure 5(e)) was created by following Hack's stream order, calculated from the DEM using the hydrological modeling tool in ArcGIS. The traditional stream order, also known as Hack's stream order or Gravelius' stream order, is a "bottom-up" hierarchy that assigns the number "1" to the river (the main stem). Stream order is an essential characteristic of a drainage basin, and it measures a stream's position in the hierarchy of streams (Hereher et al., 2020). The number of tributaries is one greater than the number of rivers or streams they discharge. Hence, all proximal branches of the main stem are assigned the number "2." Tributaries that empty into a "2" are designated with the number "3" and eventually empty into the ocean. Ranks are allocated to each stream order, with the first stream order receiving a lower ranking value of 1, and the third-stream order receiving a high-ranking value of 5.

2.2.4.1.6. Land use land cover (LULC)

The supervised classification technique in ArcGIS was used to create a LULC map of Newfoundland, which was divided into several classes (built up area, water bodies, vegetation cover, etc.) based on Landsat 8 satellite data. Based on the LULC classification map (Figure 5(f)), landfill/waste disposal sites close to any inland water bodies/wetlands, settlement areas, etc. are deemed to be more susceptible to causing environmental damage and hence are given a rank of 5 (high/very high risk), while landfill sites far away from any inland water bodies/wetlands, settlement areas, etc. are less susceptible to causing environmental damage and are assigned a lower rank of 1 (low/moderate risk).

2.2.4.1.7. Soil

The soil must have a low permeability to guarantee a prolonged movement of leachate away from the site and into the groundwater. Hence, locations that have clayey soil and limited permeability should be prioritized for landfill siting (El Alfy et al., 2010). It is possible for a landfill that has been built on top of a permeable formation like gravel, sand, or fractured bedrock to pose a severe risk to the quality of the groundwater below. Fine loamy to clayey loamy soils have a lower permeability than the sandy type of soil in the research area (Figure 5(g)). Due to its relatively moderate/low proportion of percolation/drainage potential compared to other soil types, loamy soil is known among the classes as being favorable for any waste disposal location (Bohara et al., 2019). In this study, sandy, gravelly soil has been given the highest rank, and the lowest internal rank has been given to clayey, loamy soil.

2.2.4.2. Weighted AHP data layers within the MCDM (Figure 6)

The present study applies the AHPMCDM method to assess the vulnerability of areas allocated to old and current waste disposal sites. Each environmental variable/factor is given a weight based on how important it is in relation to the ultimate goal. Decision makers determine the weights of each variable by using pairwise comparison or their expertise on the subject (Zhou et al., 2018). The AHP technique, which was created by Saaty (1980), offers a quantitative tool to use to assess the coherence of the relative weights given to each factor/variable. The AHP/MCDM methodology has been shown to be effective in mapping the vulnerability of coastal areas (Le Cozannet et al., 2013). The best MSW disposal locations rely on the views of experts regarding the various factors/criteria involved and combine their views using geospatial data analysis (Eghtesadifard et al., 2020).

2.2.4.2.1 Analytical Hierarchy Process (AHP) method

The AHP was developed during the latter part of the 1970s (Saaty 1977, 1980). The AHP is a methodology for making informed decisions in multi-criteria evaluation. It can be effectively employed with an integrated GIS to assess the vulnerability of waste disposal sites (El baba et al., 2015). The AHP was utilized to determine the relative importance of the chosen criteria through a pairwise comparison matrix. The utilization of pair-wise comparison is not limited to the ranking of thematic factor maps, as it can also be employed to rank the classes within a factor map. Thematic factor maps have been generated for each environmental variable and ranked accordingly.

Pairwise comparison matrix of AHP: (a) Priority Matrix (b) Decision matrix

AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2, 4, 6, and 8 values in-between).

Category		Priority	Rank	(+)	(-)
1	Slope	41.5%	1	30.6%	30.6%
2	Aspect	19.7%	2	23.5%	23.5%

3	Flow Accumulation	15.0%	3	13.1%	13.1%
4	Stream Order	9.1%	4	9.4%	9.4%
5	Hydrogeology	7.6%	5	6.5%	6.5%
6	Soil	4.1%	6	5.0%	5.0%
7	Land Use Land Cover	3.0%	7	4.2%	4.2%

(a) The resulting weights for the criteria based on your pairwise comparisons

Category: The criterion or category being considered in the decision-making process related to factors like slope, aspect, flow accumulation, stream order, hydrogeology, soil, and LULC. Priority: This is the calculated priority or weight assigned to each category. These priorities have been determined using the AHP. The percentages represent the relative importance of each category in the decision-making process. For example, if "Slope" has a priority of 41.5%, it suggests that this criterion carries the highest weight among all the categories. Rank: This indicates the ranking of each category based on its priority. Categories with higher priorities will typically have lower ranks, indicating they are more important in the decision context. "Slope" has the highest priority (rank 1), followed by "Aspect" (rank 2), and so on.(+) Value: This represents a positive influence or factor associated with each category. The percentages given under this column indicate the strength or magnitude of this positive factor. It is related to how much positive impact each category has on the decision being made.(-) Value: This represents a negative influence or factor associated with each category. Similar to the (+) value, the percentages in this column indicate the strength or magnitude of the negative impact or disadvantage each category has on the decision. The percentages, ranks, and (+)/(-) values all play a role in determining the overall weight of each category in the final decision.

	1	2	3	4	5	6	7
1	1	8.00	7.00	8.00	7.00	5.00	7.00
2	0.12	1	7.00	7.00	1.00	5.00	1.00
3	0.14	0.14	1	6.00	7.00	5.00	6.00
4	0.12	0.14	0.17	1	6.00	5.00	6.00
5	0.14	1.00	0.14	0.17	1	7.00	7.00
6	0.20	0.20	0.20	0.20	0.14	1	8.00
7	0.14	1.00	0.17	0.17	0.14	0.12	1

(b) The resulting weights are based on the principal eigenvector of the decision matrix

Rows and Columns: The matrix is a square matrix where the rows and columns are labeled from 1 to 7. These labels correspond to different criteria or alternatives that are being compared in the decision-making process. Values in the Matrix: The values within the matrix represent the pairwise comparisons of the criteria or alternatives. Each cell (i, j) contains a value that indicates how much more important criterion/alternative i is compared to criterion/alternative j. For example, in cell (1, 2), the value is 8.00. This suggests that, according to the decision-maker's judgment, criterion/alternative 1 is considered 8 times more important than criterion/alternative 2.Understanding the Values: The values in the matrix are typically obtained through a series of pairwise comparisons. Decision-makers assign values based on their perception of the relative importance of each criterion or alternative. These values often use a scale like 1 to 9, where 1 indicates equal importance, and 9 indicates extremely strong importance. Calculation of Weights: To determine the final weights of each criterion or alternative, the matrix is processed to calculate the principal eigenvector. The eigenvector is a special vector associated with the matrix that holds information about the relative importance of each criterion/alternative. The eigenvector associated with the largest eigenvalue is often used to calculate the final weights. In this case, the values in the matrix suggest the relative importance of each criterion/alternative. The eigenvector calculation synthesizes these values into a set of weights that reflect the overall priorities.

2.2.4.2.2 Multi criteria decision making (MCDM)

MCDM analysis is a commonly used and widely accepted statistical method for calculating weights for variables/factors and compares all identified relevant criteria of factors with one another with the aid of a preference matrix. Spatial MCDM is the process of combining and transforming geographical data into a decision (Moeinaddini et al., 2010).

2.2.4.2.3 Allocation of rank (weights) to each criterion based on MCDM

After arranging the alternatives or criteria, relative values were assigned to each class. The comparative values were determined based on a review of similar studies, expert opinion, and personal judgement. For the purpose of comparing criteria, all units were converted to the same unit of measurement scale. The ranking (comparison weights) of selected factors and criteria were assigned as per the AHP-defined mechanism in light of the procedures developed by (Fawad et al., 2022; Wang et al., 2009). Standardization was achieved by assigning a numeric value between 1 and 5 for each criterion, with 1 representing the low rate of any potential impact and 5 representing a high potential impact (Table 1).

2.2.4.2.4 Criteria weight calculation

The relative importance of hierarchical factors was determined using pairwise comparisons of all relevant weighted factors. The weighted vulnerability assessment map of waste disposal sites in Newfoundland was created by utilizing all the aforementioned input layers and the "weighted sum overlay method" of the ArcGIS spatial analyst tool. Using the AHP/MCDM approach, the relative weightage of each factor and its subclass was determined. Considering the aforementioned factors, three categories of vulnerable waste disposal sites (low risk, moderate risk, and high risk) were determined.

2.3. Results

The vulnerability analysis of waste disposal sites requires evaluating a wide range of factors that could have an effect on the water body and ocean ecosystem. Slope, land use/cover, hydrogeology, soil drainage/texture, and other variables were examined for this analysis. During the analysis, each and all variables' weighting calculations are taken into account. For the purpose of making decisions on the vulnerability assessment of waste disposal sites, it is important to integrate all the thematic layers (environmental variables) and their weighting values into a composite map. The vulnerability map (Figure 7) was classified based on four categories: "very low", "low", "moderately high" and "high." The color red on the map indicates high vulnerability, while the color light blue indicates low vulnerability. Therefore, waste disposal facilities situated in high-vulnerability areas are probably more susceptible to environmental threats than those situated in low-vulnerability areas.

Categorization of waste disposal sites as high, moderate and low risk according to environmental parameters:

Seven waste disposal sites in Newfoundland are further divided into high, moderate, and low-risk categories using the groundwater vulnerability index (Figure 8), vulnerability map, distance from water bodies, and other physiographic characteristics.

Groundwater Vulnerability Index: The data for the groundwater vulnerability index were obtained from the groundwater division, Newfoundland and Labrador in Excel file format. A groundwater vulnerability index map of high, moderate and low rank was created by converting the Excel data into point shapefiles in the ArcGIS platform. The low groundwater vulnerability index received a lower value of 1, while the highest groundwater vulnerability index was given a value of 5.

Distance/Proximity from the surface water: The buffer wizard tool in ArcGIS was used to estimate the distance between the waste disposal site and the waterbodies in Newfoundland (300, 500, and 1000 meters). The streams and lakes (https://www.geogratis.gc.ca) were taken into consideration to determine the proximity of a waste disposal site to a waterbody. Multiple buffer rings have been created around lakes, marshes, and rivers of perennial flow. Waste disposal sites far from waterbodies or coasts were considered low/very low risk, while those close to them were presumed to be at a greater risk. A buffer zone of 300 m (Hailu, 2019) was maintained around significant surface water bodies to show high risk, while buffer distances of 500 meters and 1000 meters to water bodies were used to show moderately vulnerable and low vulnerable sites, respectively (Figure 9).

2.3.1. Highly Vulnerable Waste Disposal Sites:

Based on their proximity to water bodies and streams (within a 300-meter buffer zone), steeper slopes, permeable loamy soil with good drainage, and locations at high groundwater vulnerability index, three waste disposal sites are considered to be at higher vulnerability: St. Albans, Terrenceville, and Turnip Cove's waste disposal facilities.

2.3.2. Moderately Vulnerable Waste Disposal Sites:

Three waste disposal sites are deemed to be at moderate vulnerability due to their proximity to water bodies and streams (within a buffer zone of 300–500 meters), moderately steep to very steep slopes, or permeable coarse loamy soil with good drainage: Seal Cove, Millertown and Whitbourne.

2.3.3. Low Vulnerable Waste Disposal Sites:

One waste disposal site near Charlie’s Pond is considered to be at low vulnerability given the proximity to water bodies and streams within a (>500–1000-meter buffer area), almost level to a very mild slope, or shallow coarse loamy soil with poor drainage.

2.4. Discussion

This study has taken into account a diverse range of criteria, including environmental factors, as part of its comprehensive assessment process in further choosing seven waste disposal sites, which were carefully categorized into three distinct vulnerability levels: high, moderate, and low. This classification process involved a thorough assessment that incorporates groundwater vulnerability index, a weighted sum overlay vulnerability map, and proximity to water bodies. Through this comprehensive evaluation, these waste disposal sites were systematically placed within the appropriate risk level. An attempt was made to successfully integrate the AHP/MCDM techniques with GIS technology to examine vulnerable waste disposal sites. As input for decision-making, environmental variables such as slope, soil texture, stream order, land use, land cover, and hydrogeology were chosen, and the weights for each factor were established using the weighted sum overlay technique in MCDM. The high, moderate, and low vulnerable waste disposal sites were identified using a weighted overlay analysis of the input variables. The MCDM/AHP technique provides the opportunities for planners and decision-makers to reflect their decisions more effectively and realistically. To properly investigate landfill contamination of a study area, it is important to examine environmental variables of that area. The slope of the land can affect how water flows over the surface. Steep slopes can lead to rapid water runoff, potentially carrying contaminants from the landfill into nearby water bodies, posing a risk to aquatic ecosystems and downstream communities. Understanding the existing land use and land cover helps in strategic site selection for landfills. Analyzing factors such as proximity to populated areas, water bodies, sensitive ecosystems, and potential sources of contamination allows for informed decisions that can minimize the risks of contamination. Contaminants from landfills can leach into groundwater, which is a crucial source of drinking water for many communities. Understanding the movement of contaminants through the soil and their potential to reach groundwater supplies is essential for assessing human health risks. Soil acts as a medium through which contaminants can travel. Different soil types have varying abilities to retain, filter, or transport contaminants. Studying soil properties helps determine the potential for contamination migration and its impact on surrounding environments. Ecosystem and Human Health: The interaction of contaminants with the environment can affect both ecosystems and human health. Contaminants that reach water bodies can harm aquatic life, and if they enter the food chain, they can pose risks to human consumers. Understanding how contamination spreads through these different pathways is crucial for effective management. Predictive (vulnerability) Assessment: Data on these variables/factors are essential for developing predictive (vulnerability) assessment and research. It helps in identifying potential scenarios of contamination from waste disposal sites, allowing authorities to make informed decisions about waste management practices and potential mitigation strategies. Therefore, studying these environmental factors in the context of landfill contamination provides a comprehensive understanding of how contaminants can move through the environment and impact ecosystems, water resources, and human health. This knowledge is crucial for designing effective waste management strategies and minimizing the negative effects of landfill contamination. Vulnerability assessment utilizing the weighted sum overlay method could be a viable substitute for the factor of environmental safety evaluation in terms of the landfill/waste disposal sites' impact on nearby water bodies and ecosystems. Additionally, it can be used as a guide for similar problems, especially in regions with similar geographical and environmental conditions.

To enhance the credibility and robustness of our vulnerability assessment study concerning waste disposal sites, it is imperative to incorporate real-time monitoring of soil and groundwater data in close proximity to these sites. Real-time monitoring is pivotal in ensuring that our findings are not only accurate but also up to date, reflecting the dynamic nature of environmental conditions near waste disposal sites. Furthermore, it is worth noting that the development of an advanced predictive risk model for landfills necessitates access to high-resolution topographical data and detailed hydrology, soil and geological information. Unfortunately, for Newfoundland, such comprehensive data were not readily available. This absence of environmental parameters presents a significant challenge in creating a more advanced predictive risk model, as hydrological and geological characteristics can significantly influence the behavior of waste disposal sites and their potential impact on both terrestrial and aquatic ecosystems. Incorporating the real-time monitoring of soil and groundwater data along with the acquisition of detailed environmental parameters will not only strengthen the scientific rigor of the study but also ensure that the vulnerability assessment and predictive risk model are as precise and reliable as possible, thus contributing to more effective environmental management practices.

2.5. Conclusion

To conduct this study, "vulnerability" is assessed through various environmental variables. However, environmental surface and groundwater contamination as well as other aspects are potentially sensitive elements that require additional examination and environmental monitoring to determine the possible impacts of waste disposal sites on water bodies and the ocean. The current work presents a siting method and vital support for the decision-makers in the process of resolving the waste management issue to facilitate a more in-depth comprehension of the decision-making process regarding the environment. The study contributed to a better understanding of the significance of using GIS in the process of analyzing potentially hazardous conventional dumpsites. Using this approach, the post-closure environmental management of old conventional waste disposal sites can be effectively prioritized. However, environmental and social differences should always be considered, even in similar cities. Based on probable differences, necessary changes in the development of the criteria should be made.

Declaration of Competing Interest: The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

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Table 1 Ranking of Factors (1 - Low Risk; 5 - High Risk)

Factors	Criteria
C1 Slope	Steeper slopes are scored 5 (very high impact) while flatter slopes are 1. (very low impact).
C2 Aspect	Slope is towards the ocean, and inland water – is rated 5 (high/very high impact). Rated 1 (low/very low impact) if away from the coast, or waterbody.
C3 Land use Land Cover	Inland water bodies/wetlands – Ranked 5, Tree cover/shrubland –assigned value of 1 (low/moderate impact).
C4 Soil	Clayey Loamy Soil – 1, Sandy Soil -5
C5 Hydrogeology	Sandstone/Sedimentary rocks - 5 and Granite or volcanic strata - 1
C6 Stream Order	The 1st stream order has the lowest ranking value of 1 and the 4th order is assigned highest value of 5.

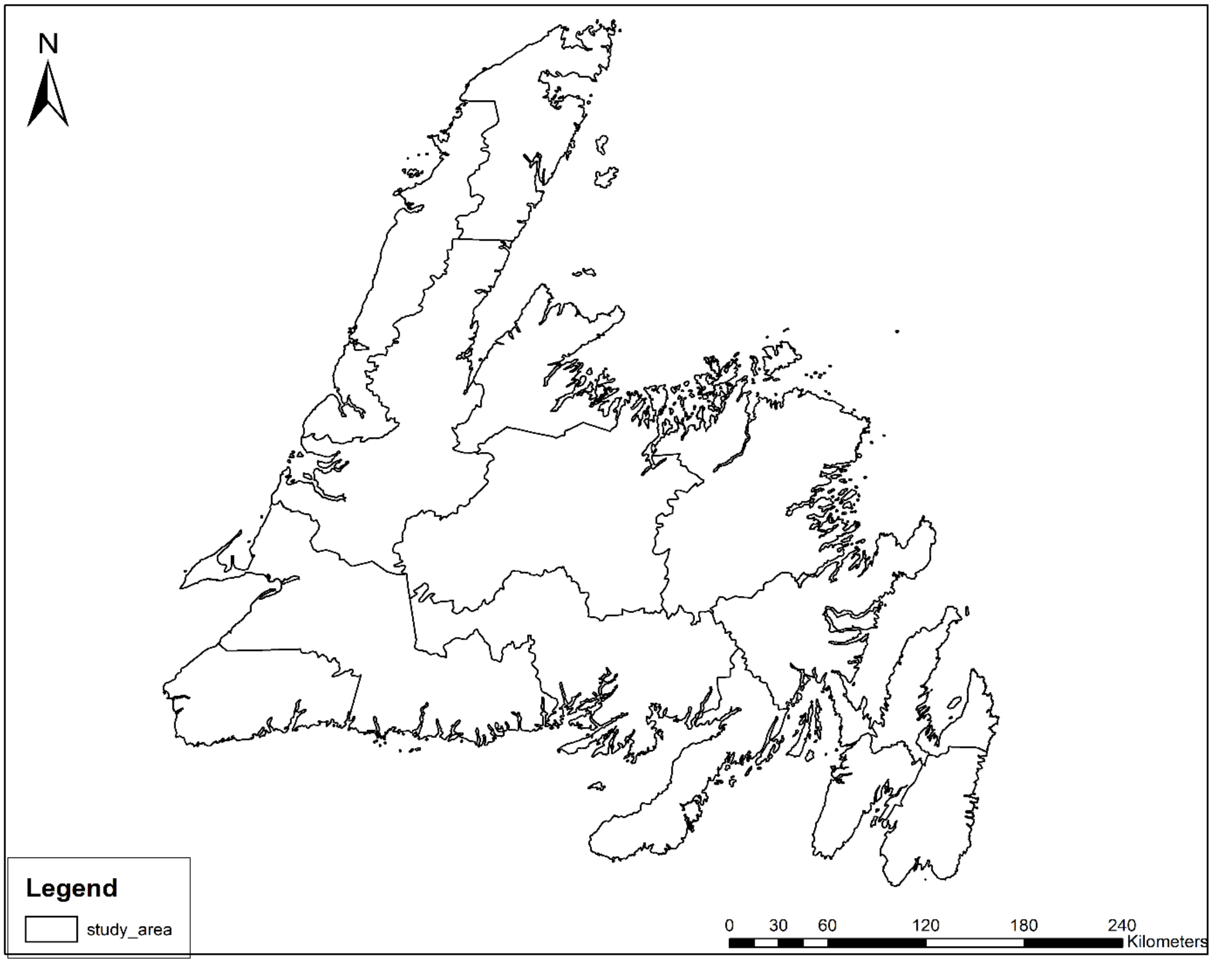


Figure 1 Study Area(Source: Author)

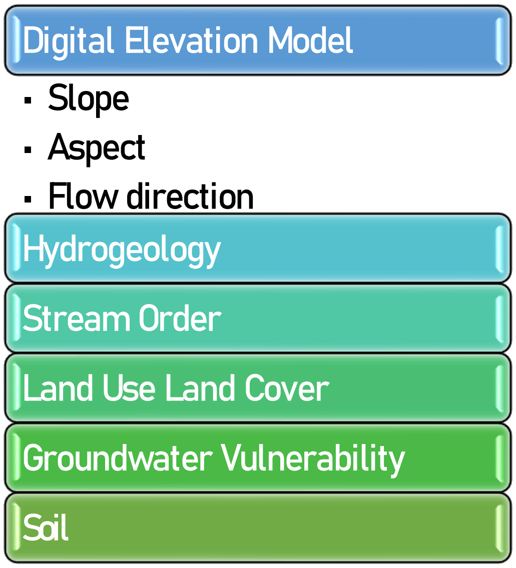


Figure 2 Flowchart of Data Variables

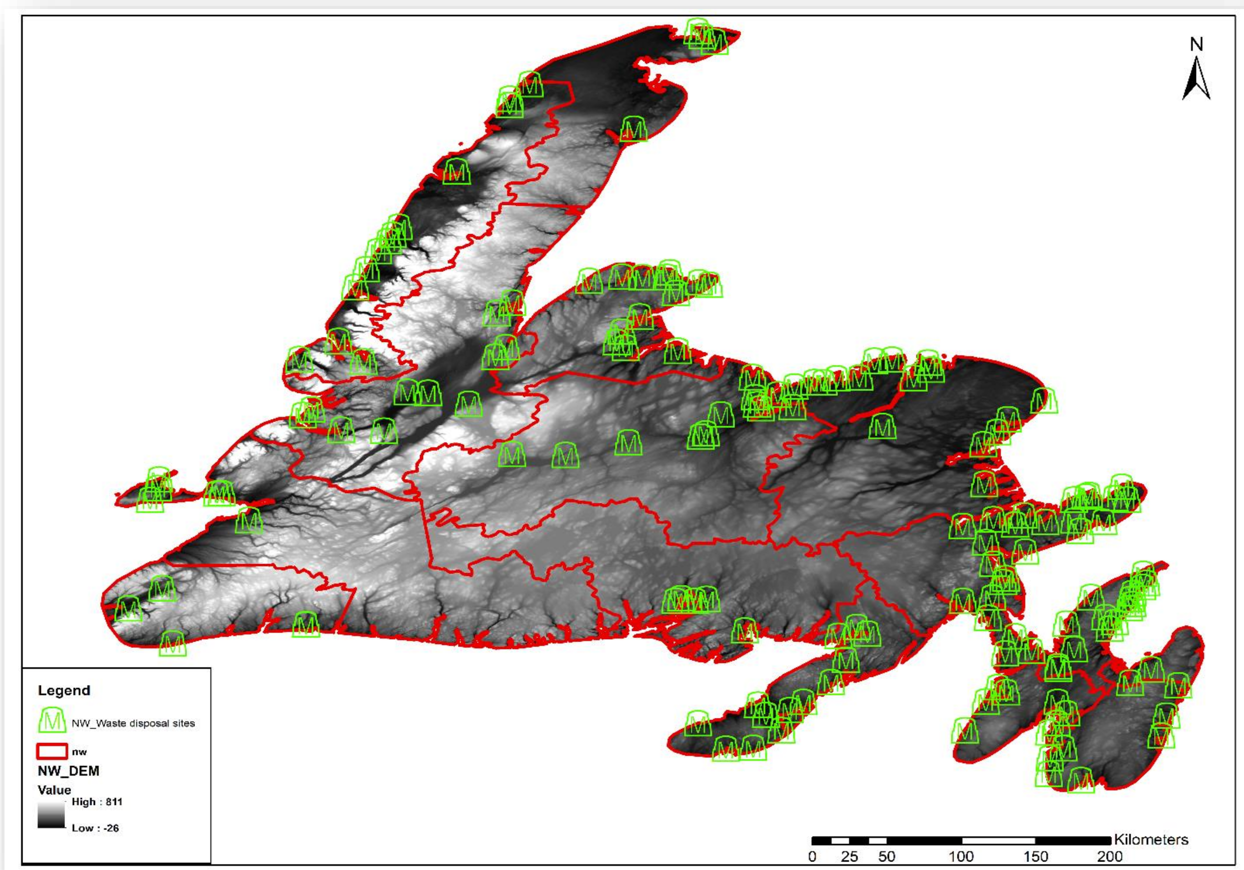


Figure 3 Digital Elevation Model with Waste Disposal Sites

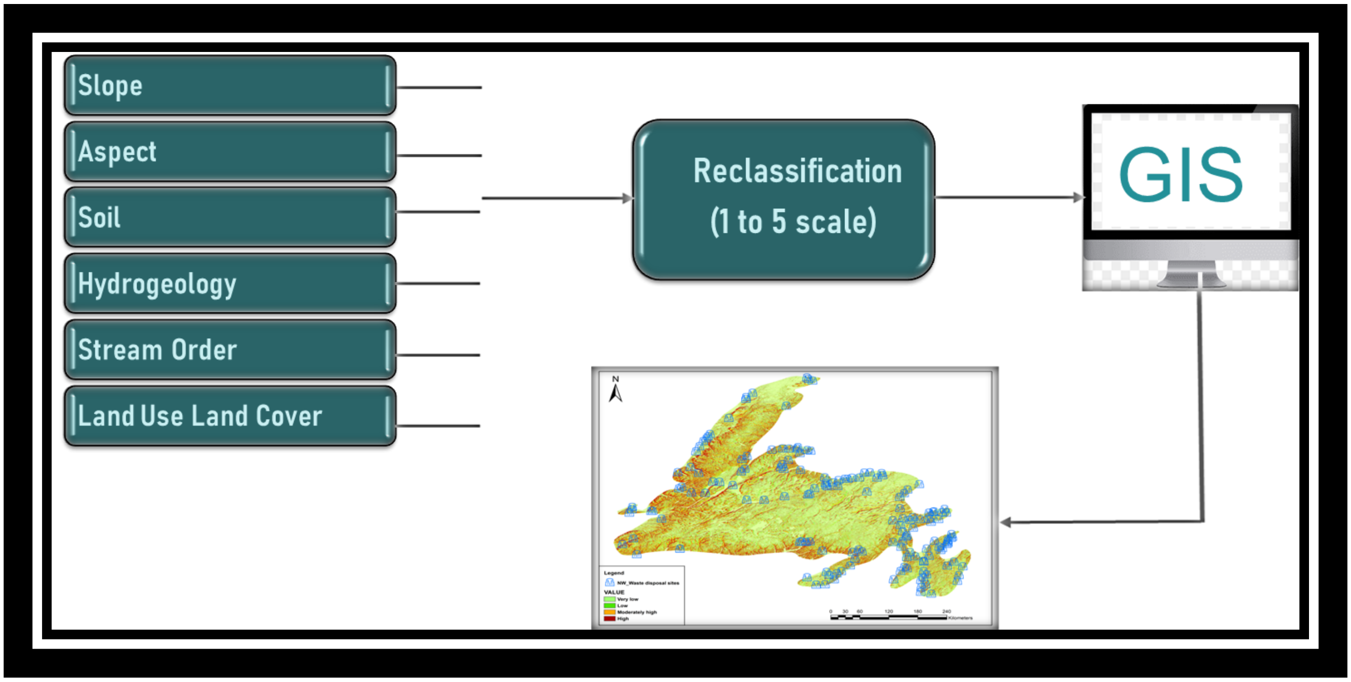
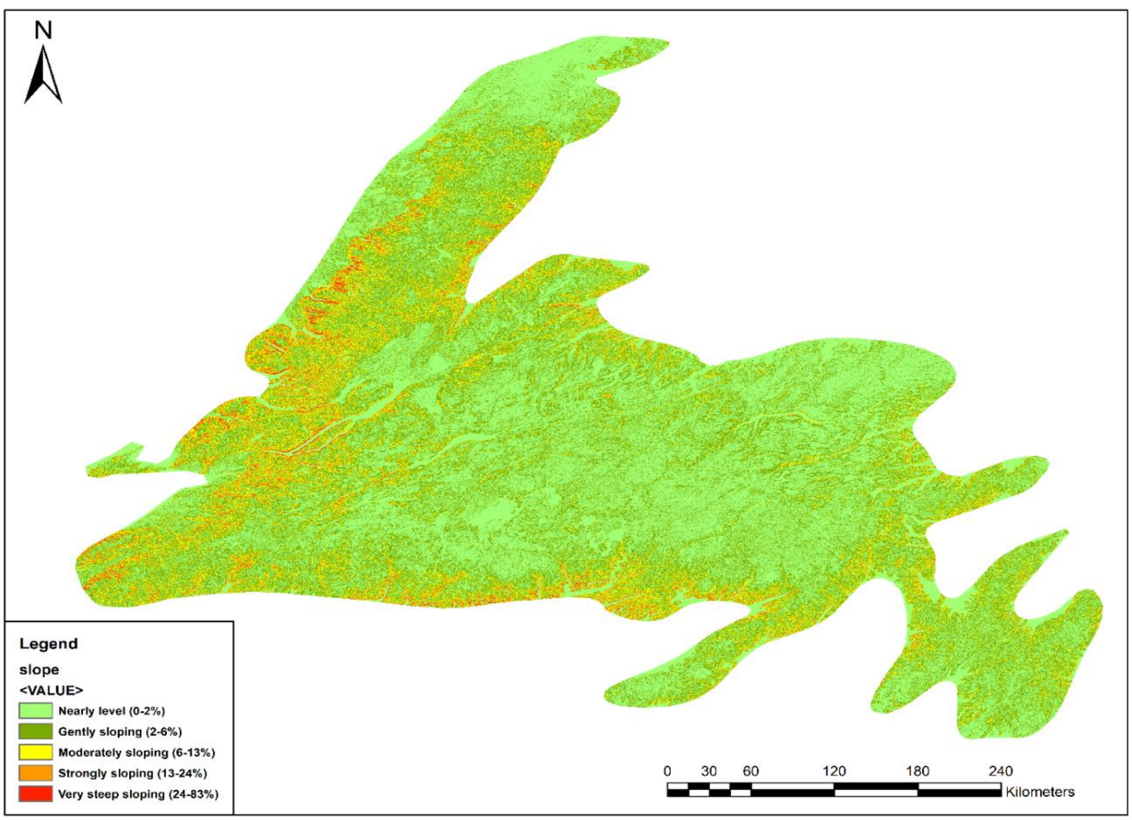
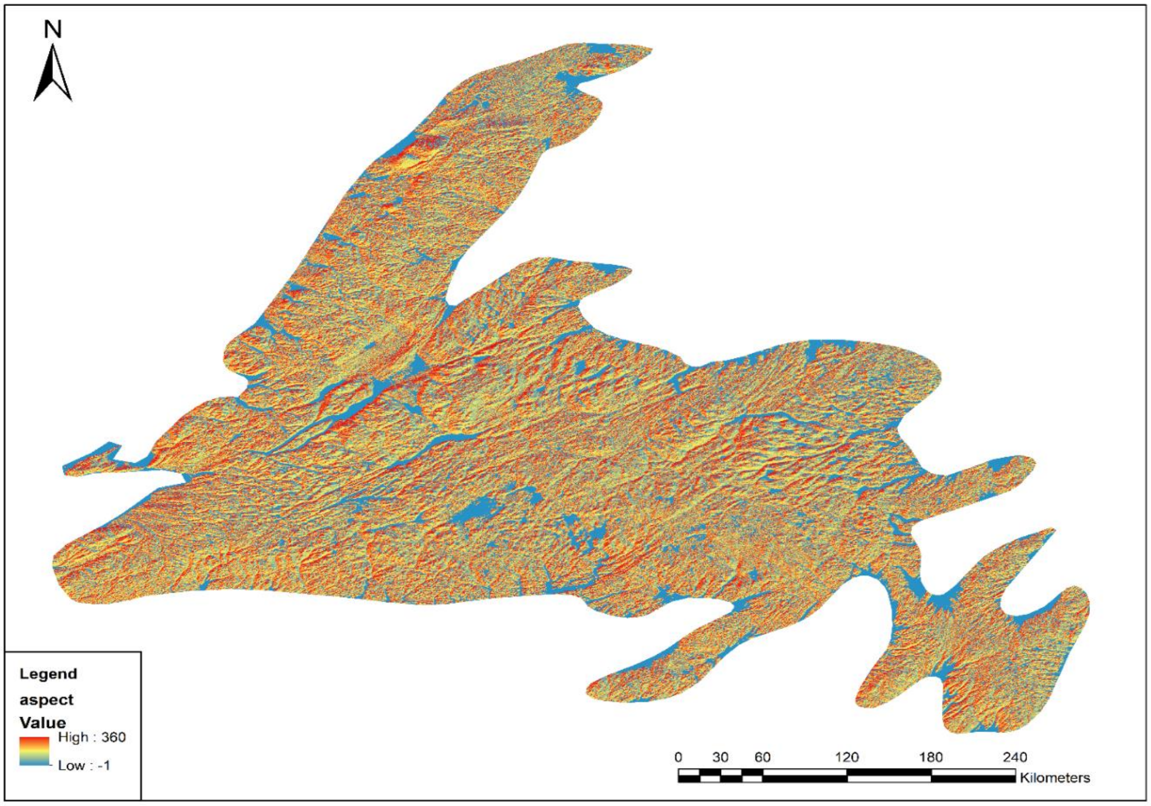


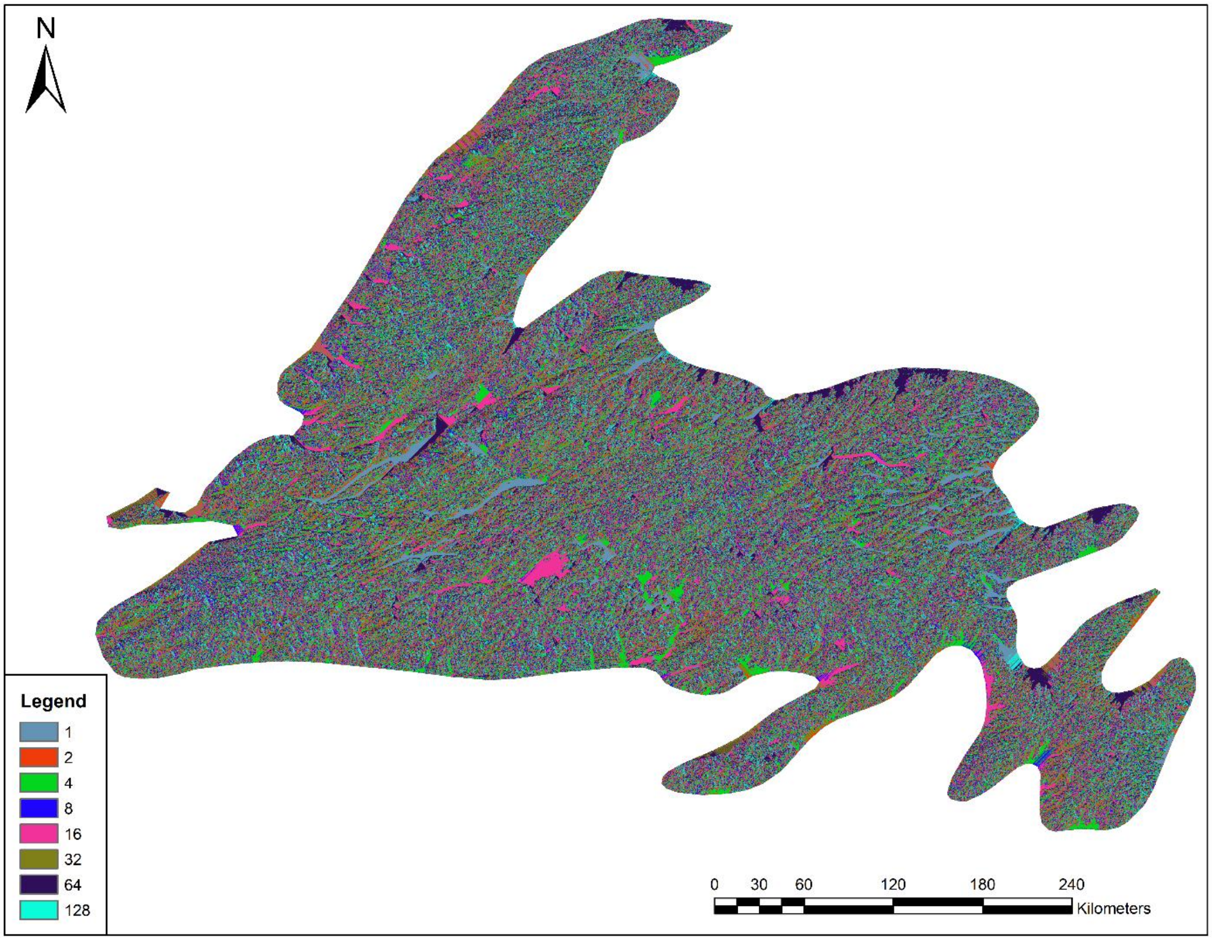
Figure 4 Methodological framework of the study



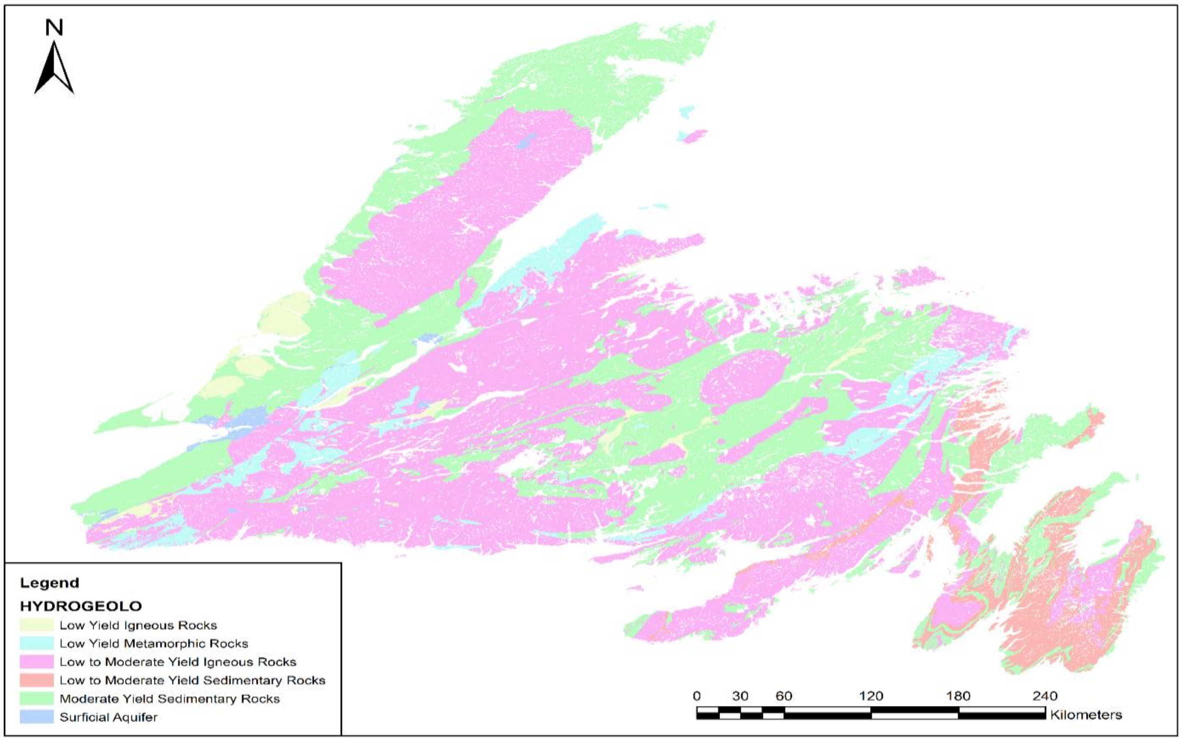
(a) Slope Map


N
Legend
aspect
Value
High : 360
Low : -1
0 30 60 120 180 240
Kilometers

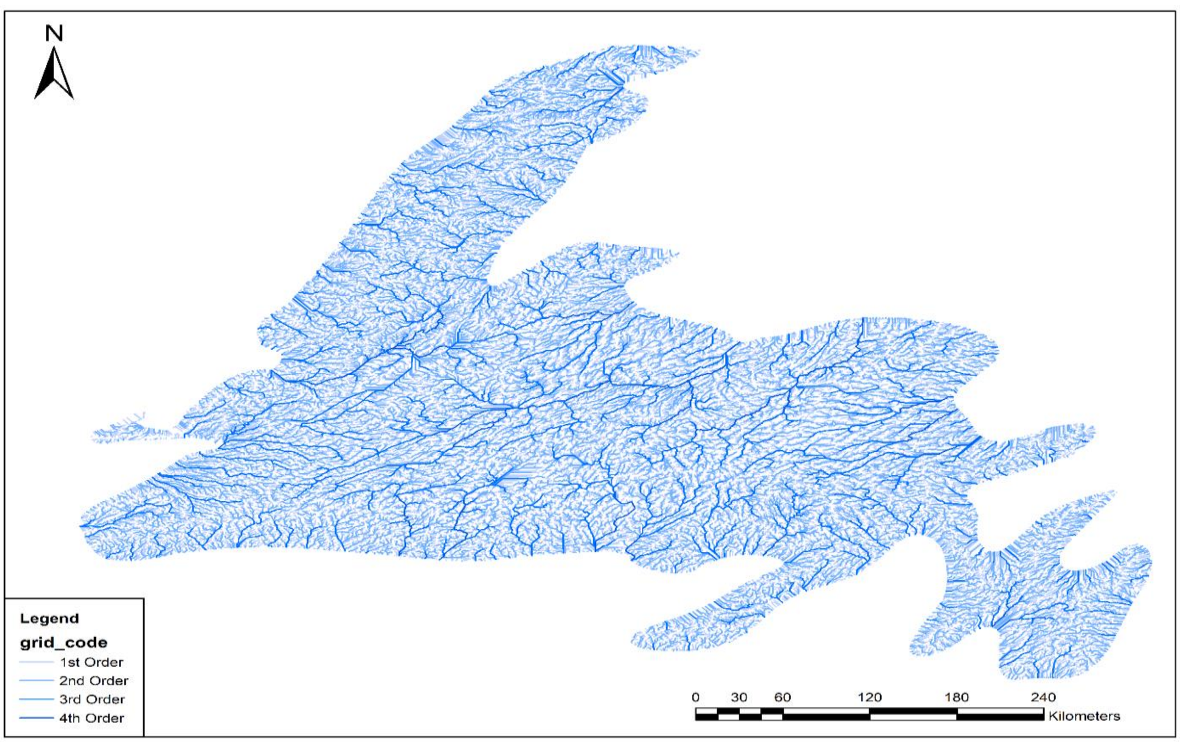
(b) Aspect Map



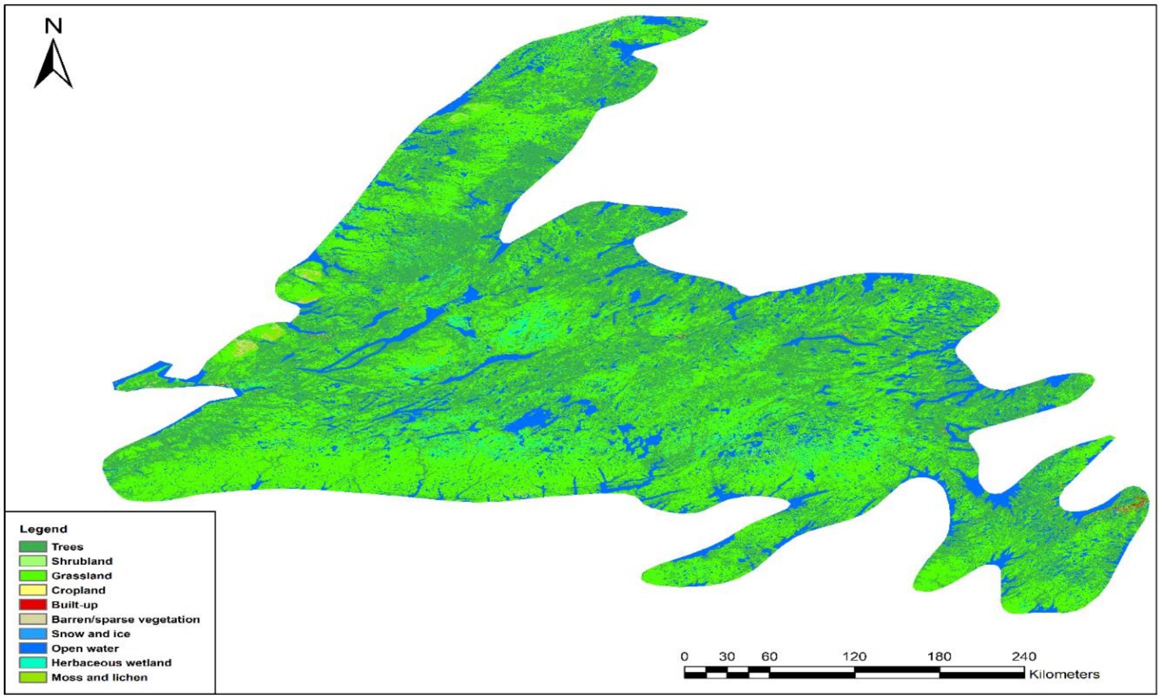
(c) Flow Accumulation Map



(d) Hydrogeology Map



(e) Stream Map



(f) Land use Land Cover Map

(g) Soil Map

Figure 5 Thematic Maps of the Data Variables. (a)Slope map (b) Aspect map (c) Flow Accumulation (d) Hydrogeology (e) Stream order (f) Land use Land cover (g) Soil.

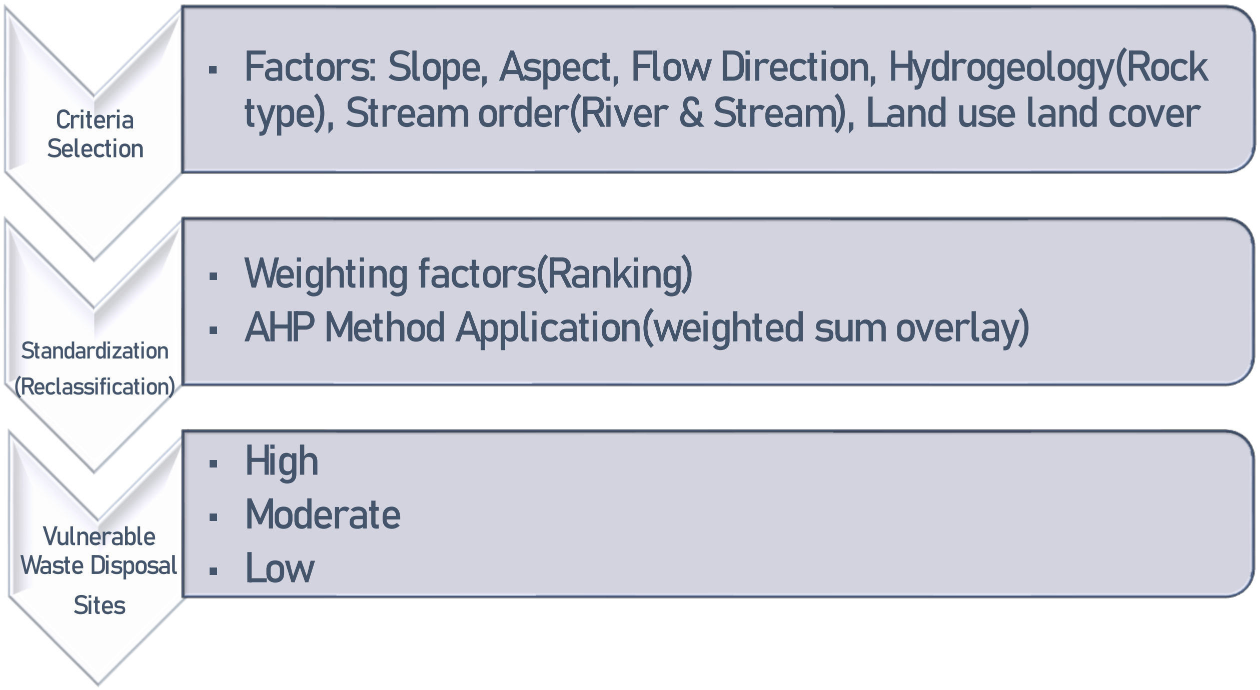


Figure 6 Data analysis and integration flowchart

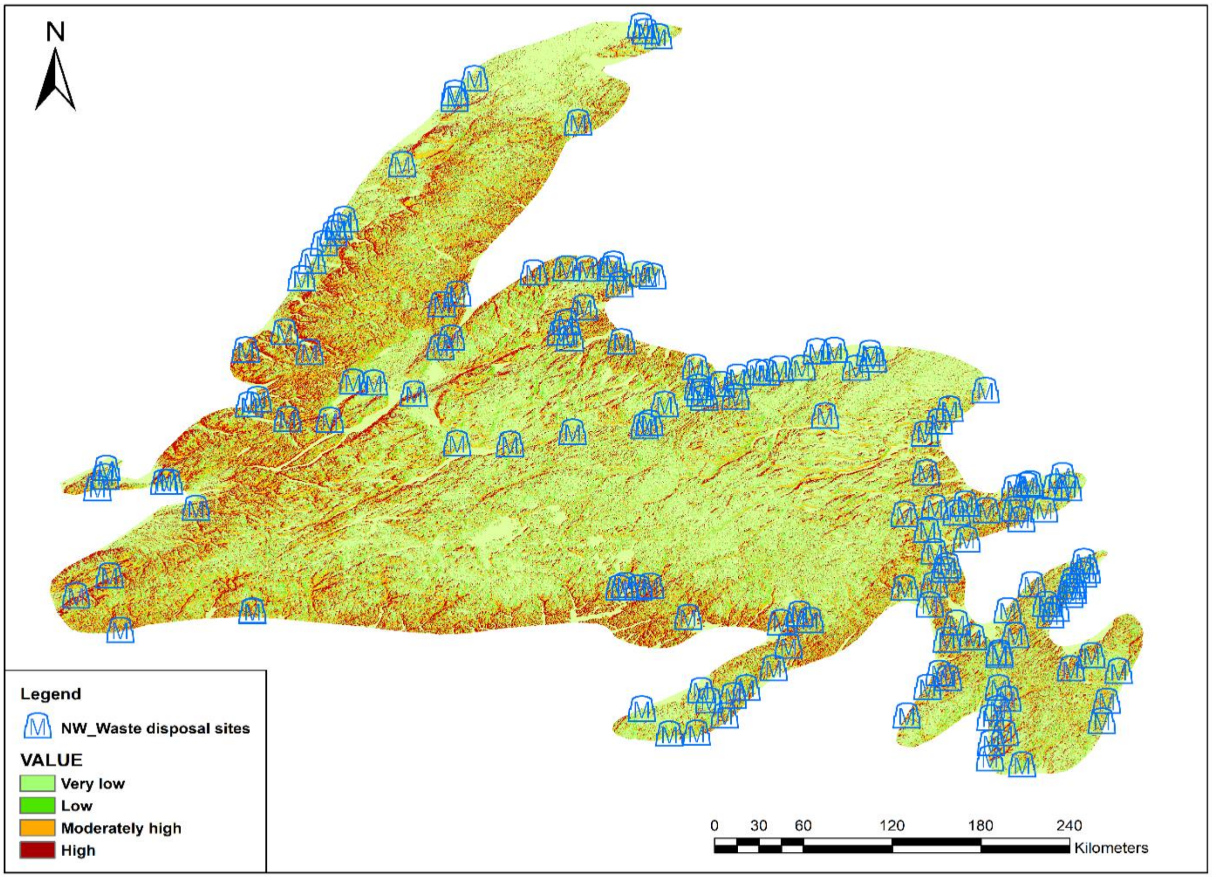


Figure 7 Vulnerability assessment map with waste disposal sites

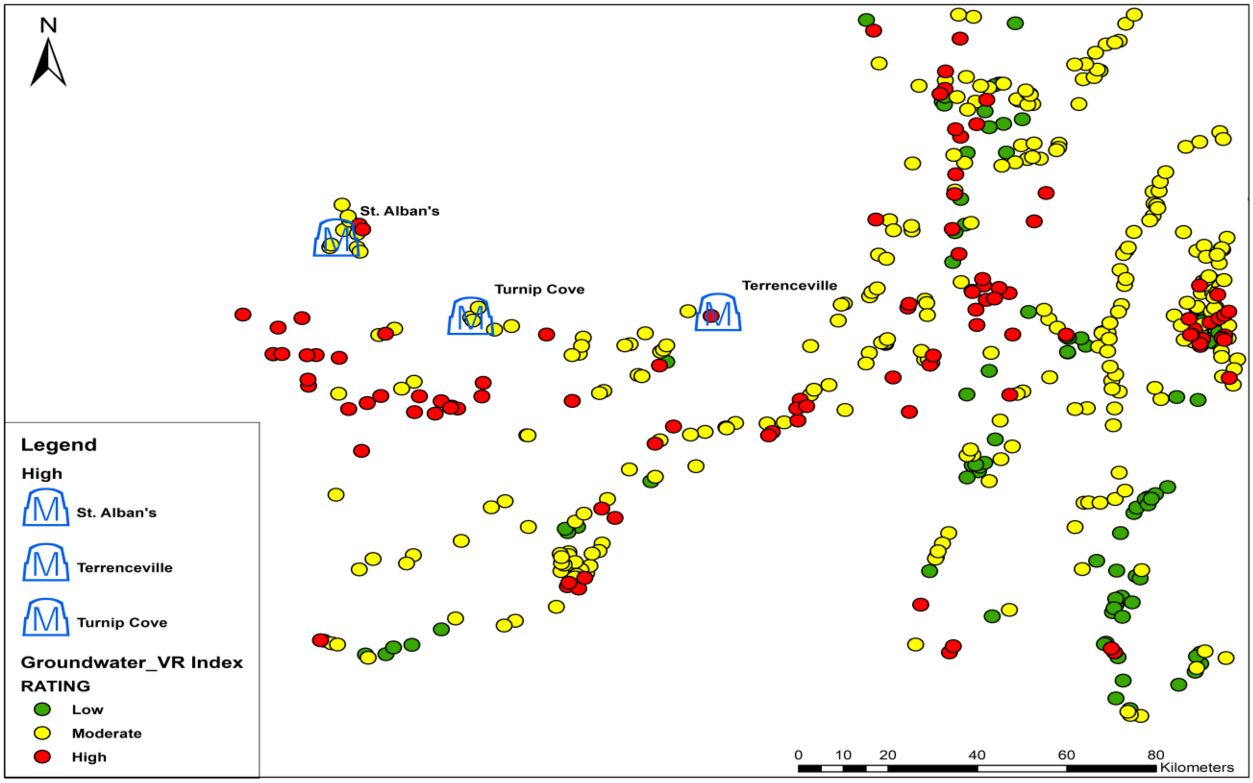
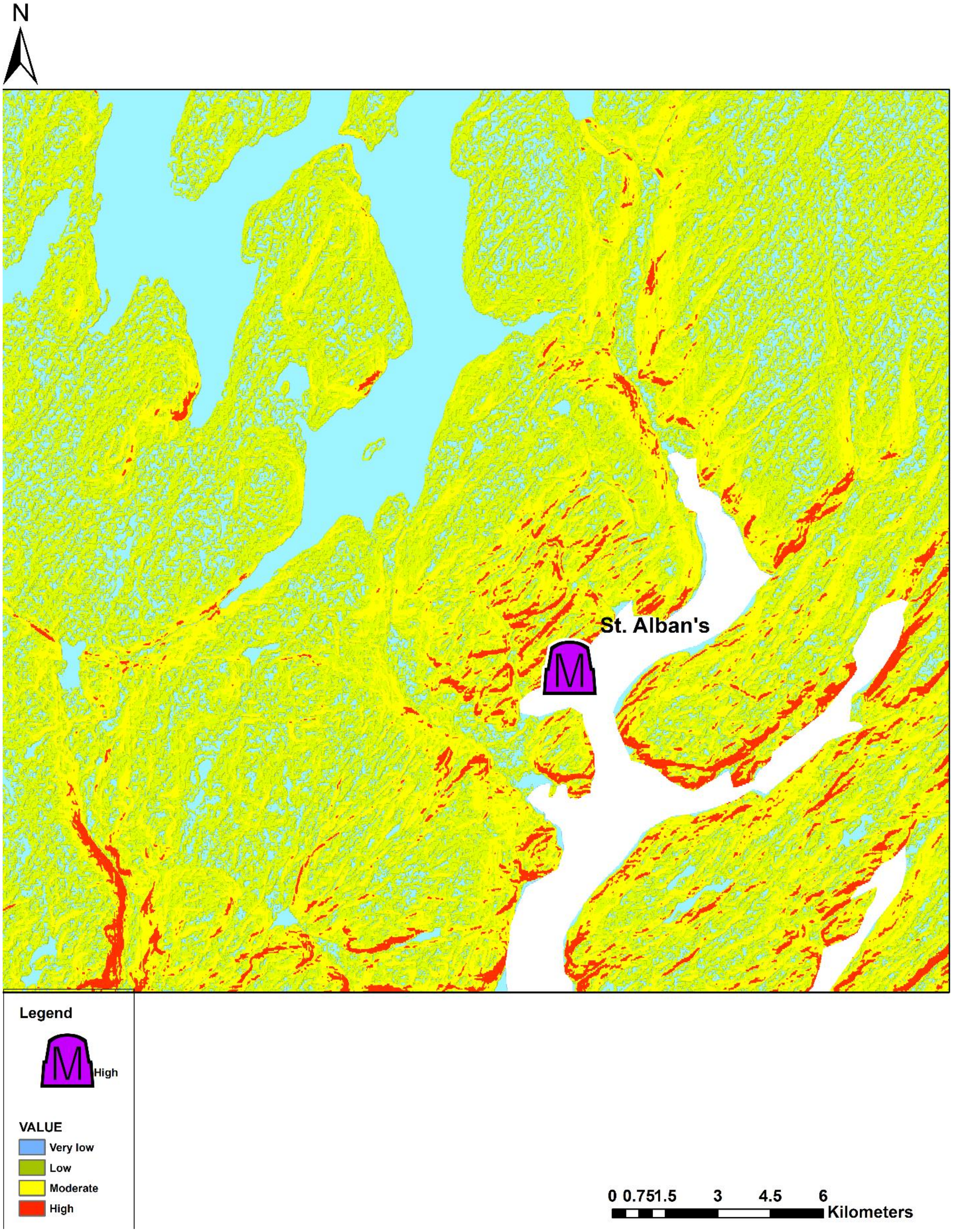
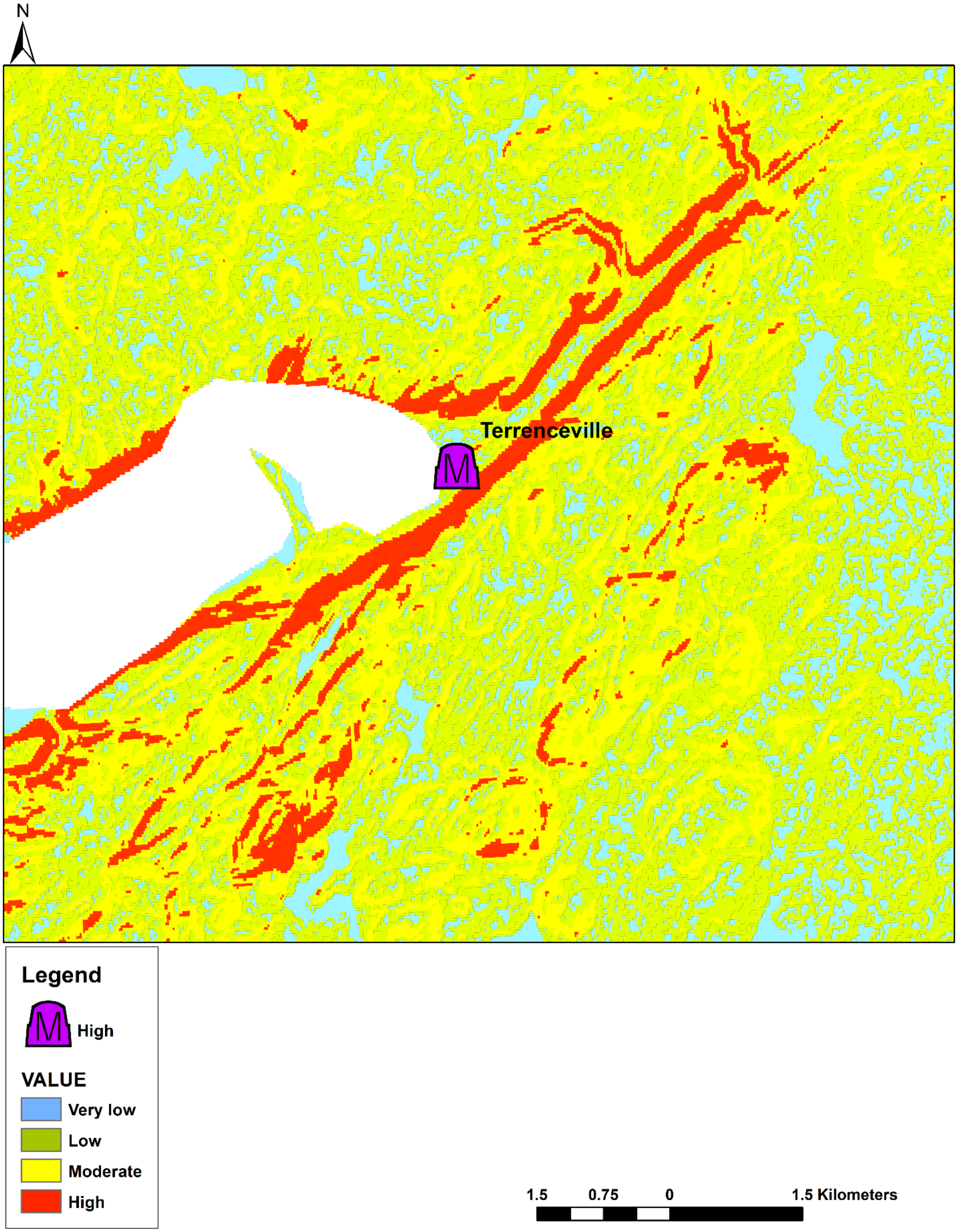
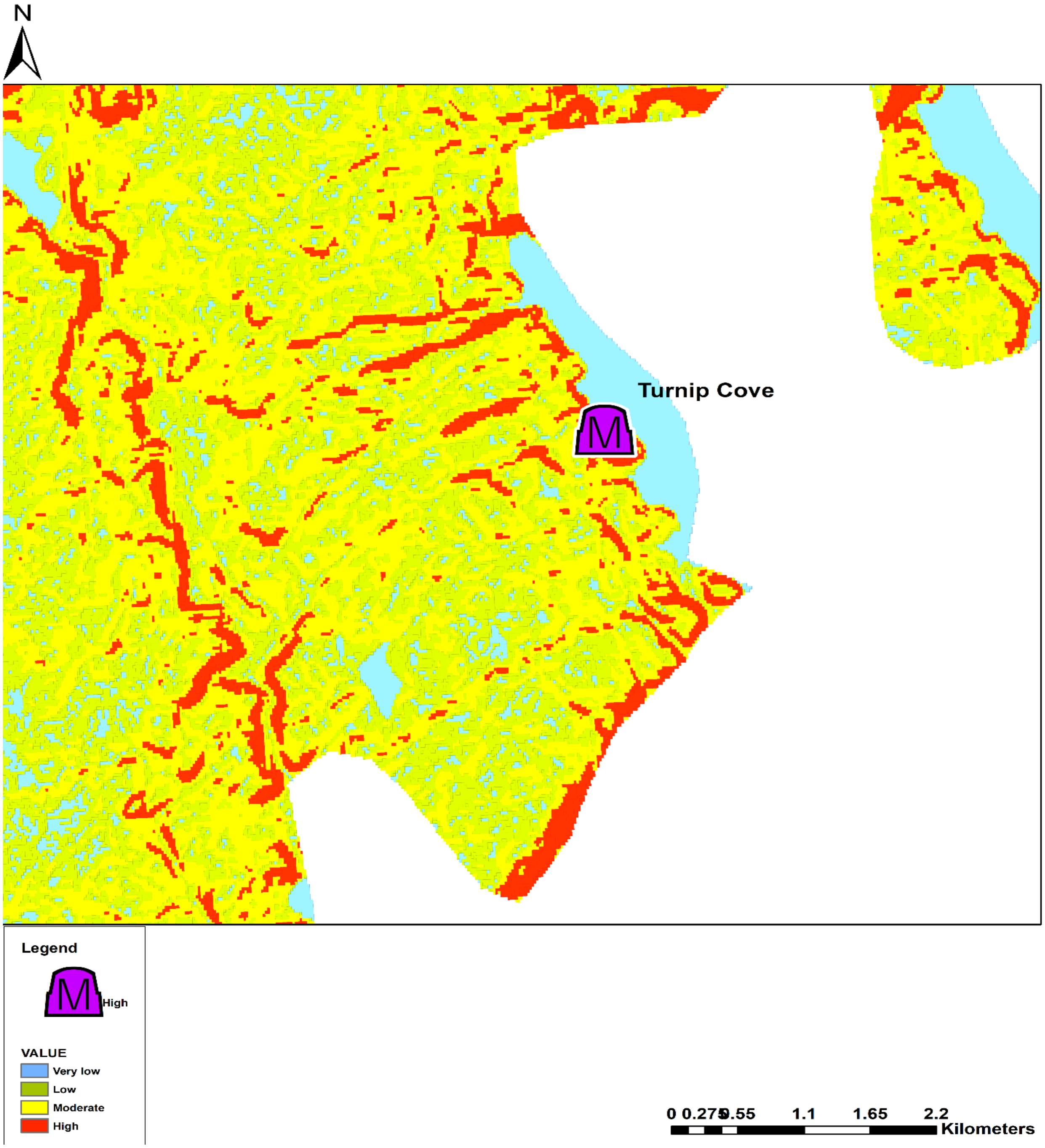


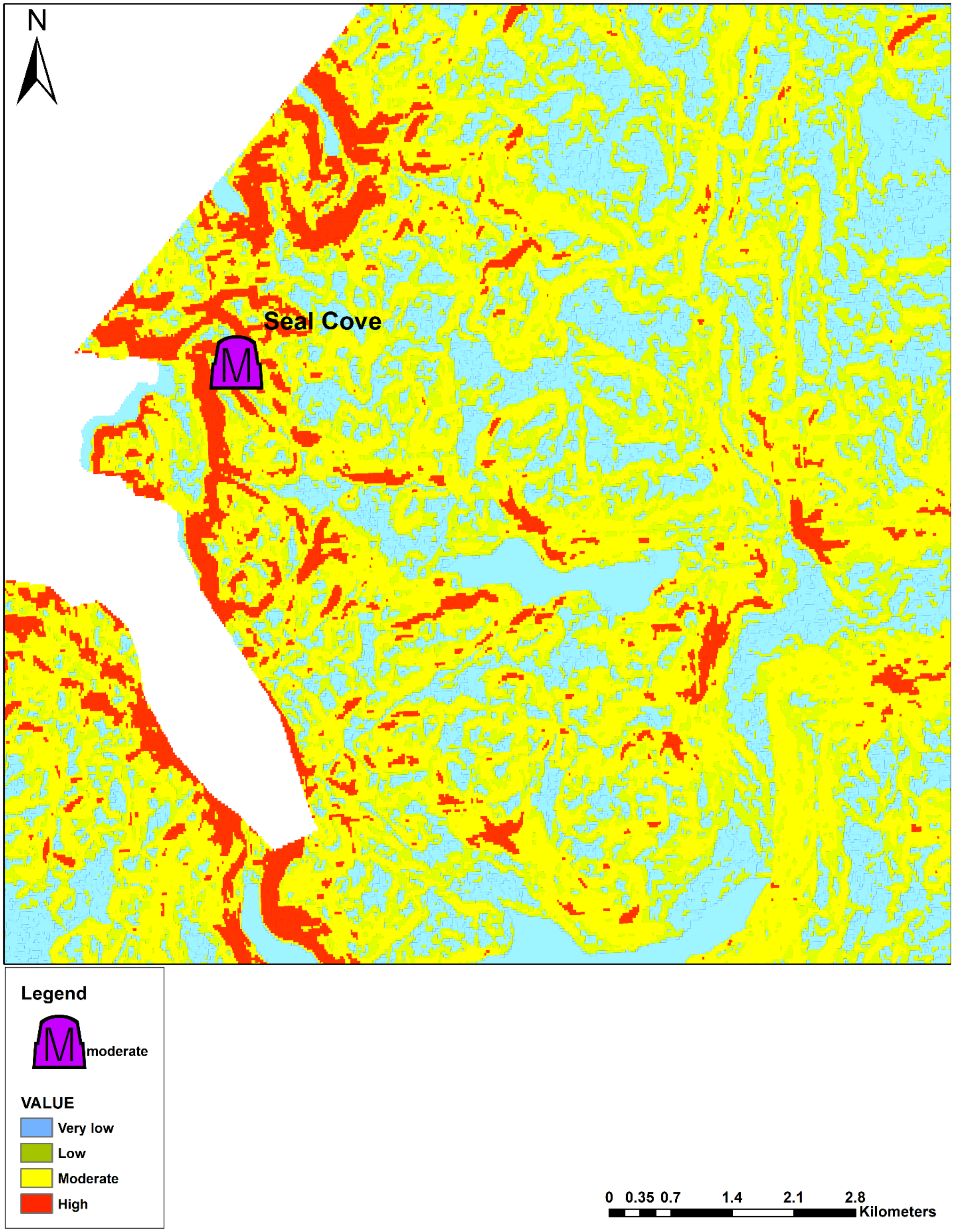
Figure 8 Groundwater vulnerability index map with waste disposal sites

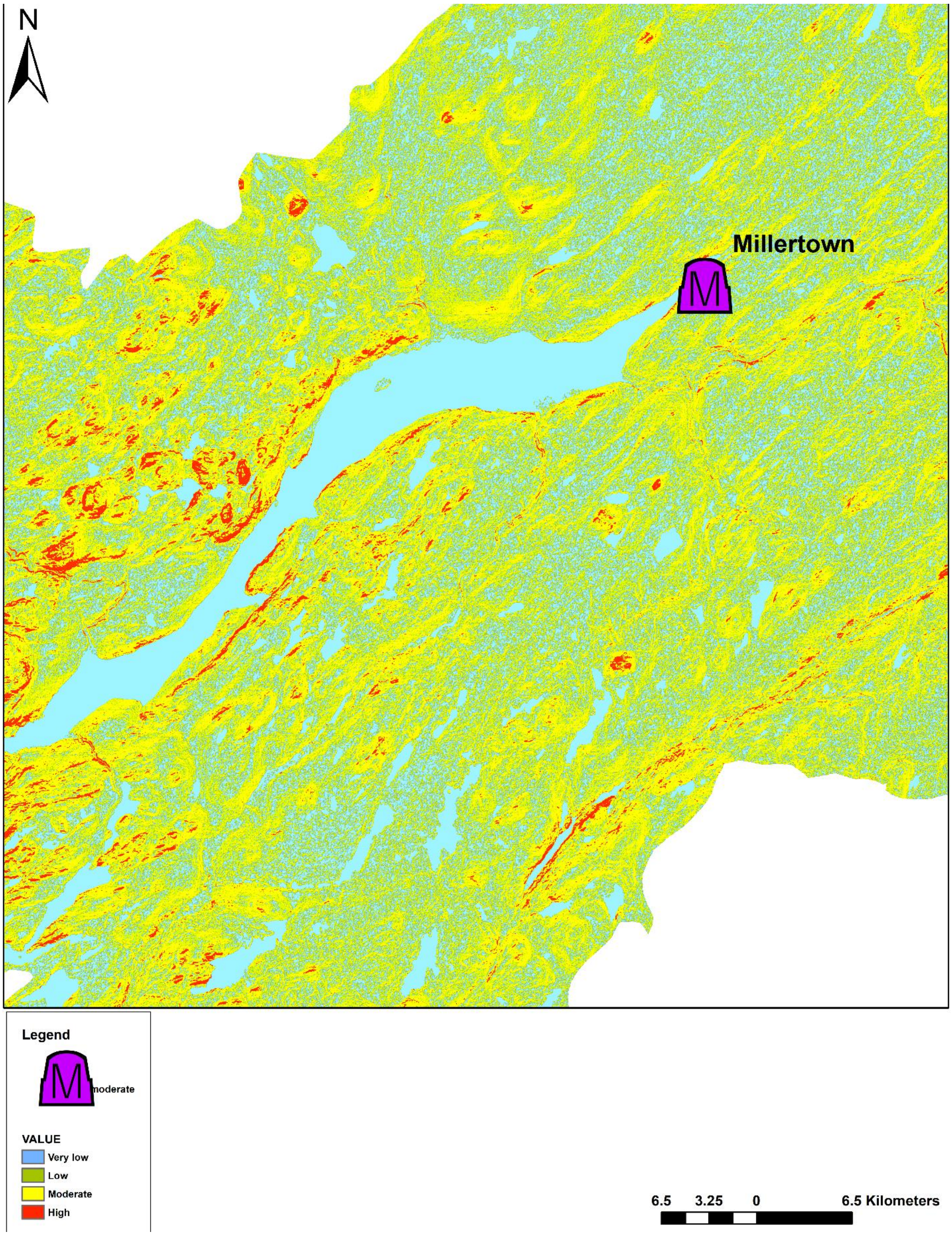

N
St. Alban's
Legend
High
VALUE
Very low
Low
Moderate
High
0 0.751.5 3 4.5 6
Kilometers

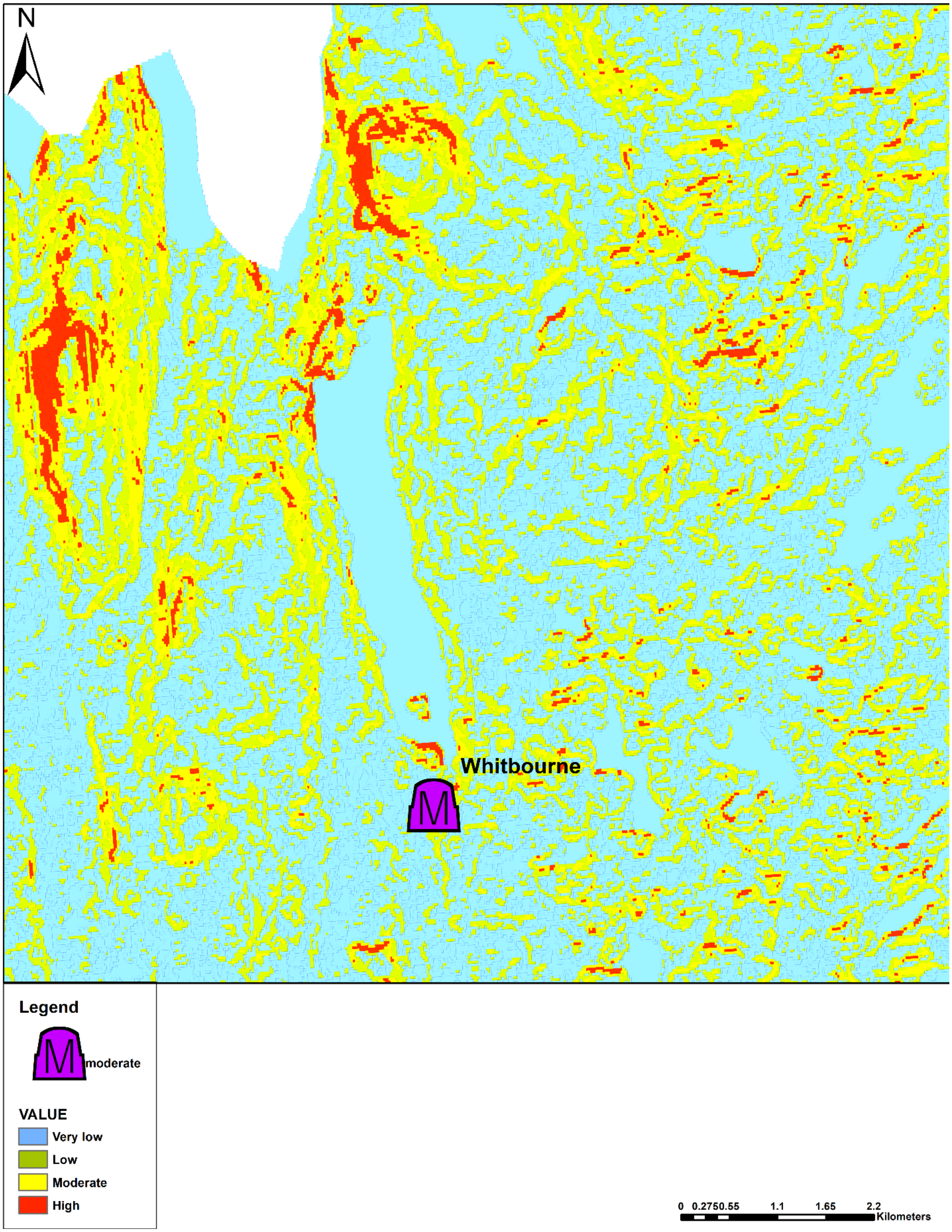

N
Terrenceville
Legend
High
VALUE
Very low
Low
Moderate
High
1.5
0.75
0
1.5 Kilometers



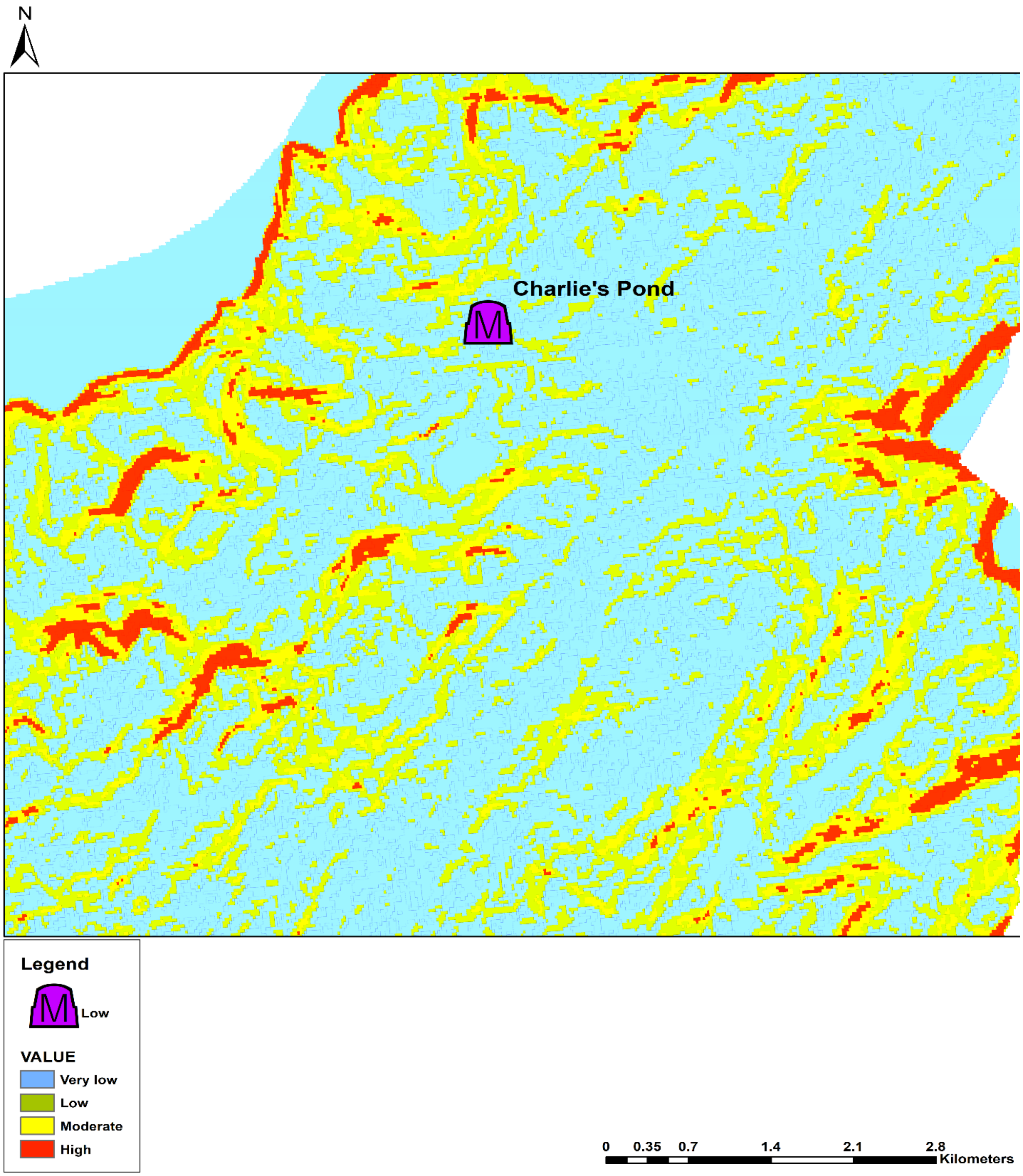
(a) High- Risk Waste Disposal Sites


N
Seal Cove
M
Legend
M moderate
VALUE
Very low
Low
Moderate
High
0 0.35 0.7 1.4 2.1 2.8
Kilometers


N
Millertown
M
Legend
M
moderate
VALUE
Very low
Low
Moderate
High
6.5 3.25 0 6.5 Kilometers



(b) Moderate Risk Waste Disposal Site



(c) Low-Risk Waste Disposal Site

Figure 9 (a) High-risk waste disposal sites (b) Moderate-risk waste disposal sites (c) Low-risk waste disposal site

Chapter 3: A public perception study on the possible environmental and health impacts of waste disposal sites on the water bodies and ocean ecosystems of Newfoundland.

Unpublished, prepared in manuscript format for potential submission to Waste Management Journal

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Abstract

Any environmental and social issue that involves public engagement can increase social fairness, identify problems, and ensure that the general public's concerns and aspirations are consistently acknowledged and taken into consideration by decision-makers. The purpose of this study was to comprehend and evaluate the common perceptions, ideas, and opinions of the public on the potential environmental and health impacts of landfills and waste disposal sites on water bodies and the ocean ecosystem in Newfoundland (Canada). Community members, town councilors, mayors, landfill managers, public health officials, environmental scientists and engineers, provincial government officials, recyclers, and waste disposal service providers were among the 32 participants involved in the study. NVivo14 software was used to generate themes from the participant's recorded interview once it was properly transcribed. The study aimed to investigate perspectives from diverse stakeholders regarding the existing waste management scenario in Newfoundland. It sought to understand their viewpoints on the potential health and environmental risks linked to the current waste management practices. The study's observations point to a knowledge gap between the general public and authorities who are involved in waste management and planning. It is critical for the relevant authorities to establish a more accessible system for educating the general public about waste diversion initiatives and advice on the health implications of improper waste disposal.

Keywords: Waste disposal sites, Public perception, Waterbodies, Environment, Health, Thematic analysis.

3.1. Introduction

Canada generates one of the highest amounts of per capita waste in the world (Sevunts, 2019), with 694 kilograms of garbage produced per person yearly; of this amount, 510 kilograms are diverted from recycling facilities and disposed of in landfills. Newfoundland and Labrador (NL), one of the Canadian provinces, produces 400,000 tons of waste annually, or around two kilograms per person every day, which translates to about 730 kg/year per capita (Department of Environment, 2019). Previously in NL, waste was sent to 240 disposal facilities that served 654 communities. Currently, there are only two regional disposal sites (Norris Arm in the central region and Robin Hood Bay in the eastern region), and the western region has chosen to send its waste to Norris Arm. Labrador City and Wabush are served by a new landfill in western Labrador (Municipal Affairs and Environment, 2017). Historically, landfills were often located in low-lying coastal locations. These landfills were not constructed with leachate management in mind. Closed and post-closure repurposing of such waste sites could pose a number of environmental problems if proper closure protocols are not followed. This may lead to problems such as the release of hazardous and non-hazardous compounds, unpleasant odors, and gas into the nearby soil, water bodies and air (Victoria, 2022). Since 2002, 72% of the older garbage disposal sites in the province have been closed (Municipal Affairs and Environment, 2017). Nonetheless, due to their close proximity to the coastline, these sites may still hold the potential to pose environmental risks. Consequently, it is imperative to conduct regular monitoring of both soil and groundwater within and in the vicinity of the waste disposal sites. The management of solid waste is an enormous challenge for municipalities. Prior research has indicated that ongoing population growth, coupled with concurrent urbanization trends and the expansion of conurbations will further exacerbate the already substantial challenge of solid waste management for municipalities (Alavi et al., 2013). Hence, sustainable waste management requires ongoing support from the community, and a positive public perception of landfill operations can contribute to the long-term sustainability of these facilities. The reinforcement of waste management regulations and policies is realized through a collaborative approach, which includes the active participation of working groups, community stakeholders, and regional authorities (Adekola et al., 2021). This study is designed to investigate the public's views and perspectives regarding the potential environmental and health consequences of waste disposal sites on aquatic ecosystems, including water bodies and the ocean in Newfoundland.

In Canada, provincial and territorial authorities are responsible for the establishment and management of waste reduction policies and initiatives as well as the approval and control of waste disposal facilities and operations. The federal government regulates the out-of-province movement of hazardous material, waste, and recycling (Government of Canada, 2002). Regardless of the fact that more waste is being reused, recycled, or energetically valorized, landfills continue to be a crucial part of waste management systems, and even though modern engineered landfills are built to contain harmful waste, leaks occasionally occur (Pecci, 2018). As a result, landfills continue to pose a threat to both human health and the environment. There is a potential for humans and other species to be exposed to contaminants in landfills (Essien et al., 2022). Leachate from landfills can also introduce contaminants into the groundwater if there is a leak (Abiriga et al., 2021). Therefore, waste management policies have to be implemented in ways that successfully balance between economics of disposal and community and environmental health. It is essential to ensure that NL has effective waste management practices to prevent any possible environmental damage from both open and closed landfills.

Electronics, paints, and household cleaning products are examples of manufactured goods that can release toxins into the ground as they slowly decompose. As rainwater and melted snow passes through the waste in landfills and other unmanaged areas, it picks up pollutants. It has been noted that heavy metals, including mercury, lead, arsenic, copper, and zinc, are only a few of the pollutants that build up in the soil beneath landfills (Schader, 2021).

The value of public participation with regard to environmental policymaking has been widely acknowledged. Environmental concerns are best managed with the participation of all interested individuals at the relevant level, as stated in Principle 10 of the Declaration of the United Nations (UN) Rio Conference on Environment and Development (1992) (UN, 1992) (Environment, 2018). In terms of social, economic, and environmental outcomes, increasing public knowledge of household waste management is a cost-effective strategy. Waste management that is up to date and effective reduces consumerism, increases social justice and overall economic efficiency, and supports natural resource conservation (Zyadin et al., 2020). Therefore, this study attempts to understand how the public feel about the efficiency of the current system for handling solid waste in the province. The study seeks to evaluate the perspectives of experts, such as environmental scientists, health officials, waste management officials, and other stakeholders, the likelihood of the contamination of water bodies and ocean ecosystems from waste disposal sites and the subsequent impact on local seafood. Concerns with prevention efforts, ways to improve decision processes, the control and management of waste operations and how to enhance understanding of their impacts, and suggestions for addressing waste management issues are presented in the study.

The authors are unaware of any study in NL on the public perception of the effectiveness of waste management and the potential influence of waste disposal sites on adjacent water bodies or ocean ecosystems as well as their potential impacts on local seafood and their consumption. The aim of this study was to gather the opinions of significant stakeholders and concerned authorities regarding the health and environmental impacts of waste disposal sites and the current waste management situation in Newfoundland. This research is expected to provide valuable insights for waste management officials, municipal authorities, and decision-makers that will enhance the efficiency of consensus-building approaches when it comes to formulating plans and making decisions regarding future waste disposal site selection and management.

3.2. Methods

3.2.1. Study Area

The island of Newfoundland, excluding associated islands, is approximately triangular in shape and covers an area of 108,860 square kilometers (as depicted in Figure 10). The predicted population in 2023 is 477,787. Newfoundland generally has cold but not severe winters and warm to cool summers due to its close proximity to water.

3.2.2. Study Design

The Interdisciplinary Committee on Ethics in Human Research approved the study design (Figure 11) and questionnaire (Appendix C) (Certification Human Ethics, File No. 2022540) on 6 June, 2022. A series of questionnaires containing in-depth questions about waste management, the potential effects of waste disposal sites on the environment and water bodies were developed for environmental engineers, scientists, provincial government officials, public health officials, community members, town mayors, landfill managers, recyclers, and landfill site employees. The interview questionnaire (supplementary file) was framed with the goal of the study in mind and was inspired by the validated questions from previous research articles on public perception studies of waste management (Zagozewski et al., 2011; Zhang & Klenosky, 2016; Greenberg et al., 2012). Before conducting interviews with participants, a pilot test of the questions was conducted in-house. The purpose of the questionnaire for community members was to determine the general public's perspective on waste management, their familiarity with waste diversion programs, and any general concerns regarding the potential effects of waste disposal sites on nearby water bodies and whether or not they might affect their consumption of seafood. The majority of the questions for town managers and waste management professionals focused on waste diversion initiatives, waste management/treatment facilities, and current municipal solid waste services in the province. Environmental scientists, government officials, and public health officials were questioned about the potential environmental effects of waste disposal sites; the impact on the quality of the air, water, and soil; and any connections between the contamination of water bodies with waste and human health and the consumption of seafood. The questionnaire for garbage collectors and recyclers assessed their involvement in the collection of recyclable material and its logistical management (electronic waste, used oil cans, paints, etc.). The participants for each set of questionnaires were reached via email and social media sites such as Facebook and Twitter by distributing the research study's poster on the official social media accounts of the following organizations viz Social Justice Co-operative NL, Zero Waste Canada, Municipal NL, the Atlantic Used Oil Management Association, and the Electronic Products Recycling Organization.

A total of thirty-two participants were recruited for the study, including eleven community members[2], four environmental scientists/protection officers, seven provincial government representatives, three health authorities, three recyclers/waste collectors, and four

[2] Community members were demographically categorized (based on age, gender, work status, location, and length of residency) (see Appendix: Table 1).

waste management officials/town managers. Each participant interview was performed through telephone/Webex© and recorded with their consent. All interviews were semi-structured, which allowed the interviewer to ask open-ended questions about the perception and experiences of the participants. The length of the interviews ranged from 15 to 25 minutes.

3.2.3. Data Preparation and Analysis

For every group of questionnaires, the recorded interviews were manually transcribed. Following NVivo14©'s processing of the interview transcripts, separate categories were created for each set of derived transcripts (for community members, environmental scientists/engineers, public health officials, waste management officials, etc.) based on participants' subjective responses, which aided in the creation of some preliminary codes. Different responses from the participants were used to generate emerging codes. The resulting codes were initially organized into themes and then into subthemes (based on previous knowledge, current research, and/or theory) using a deductive approach (Table 3). Thematic analysis (Braune and Clarke, 2006) is typically carried out on derived data because the themes were based on subjective information such as a participant's experiences, perspectives, and opinions on waste disposal sites, municipal solid waste management and potential environmental and health impacts of waste. The software used an iterative memo[3] process to create the themes from the primary codes. In generating themes, direct quotations from the participants were prioritized and supplemented by the author's interpretations and contextual information (Bourgeault et al., 2010).

3.3. Results

The transcripts are categorized into the following primary themes and sub themes:

[3] Memos allow recording of the project's thoughts, interpretations, and understanding. They help to keep analysis separate from but related to the material the user is examining.

Primary Themes: Waste Management - As Public Perceive, Environmental Impacts of Waste Discharge, Influences of Dumpsite Runoff on Ocean Ecosystem, Concerns about Human Health and Contaminated Seafood, Public Education/Awareness and the Role of Modern Technology in Waste Management.

3.3.1. Waste Management - As Public Perceive

Public opinion could play an important role in the proper siting of waste disposal facilities and the provision of waste management services. Community involvement is crucial for the proper functioning of municipal solid waste facilities.

During the interview with the community members, a concerned citizen provided insights into the waste management services offered by the local municipality. In St. John's, these services encompass routine garbage collection and curbside recycling. However, for hazardous materials such as paints and other similar items, a distinct collection process is in place at the provincial level. Notably, the Central Transfer Station is responsible for managing household garbage and recycling, while residents may need to transport other types of waste to the Robin Hood Bay facility in the city of St. John’s. Curbside recycling and garbage collection services are available, but the disposal of electronics is not as convenient. There are designated locations where one can personally drop off electronics, beverage cans, and paint, as mentioned by another community member. However, some individuals voiced their concerns about the effectiveness of current waste management services.

> *“It was really difficult to keep up with household waste when the city was on strike over the summer- especially for those without vehicles…we live near… so we are worried about the diversion of rats and more garbage around…there’s an increase in rats over the last 2 years”.*

Community members held the belief that the city's composting capabilities could be enhanced. Several individuals shared their experiences with backyard composting, noting a consistent issue with rat infestations. It is highly probable that the introduction of a city-wide composting program would yield significant benefits.

3.3.1.1. Sub themes -

3.3.1.1.1. Waste Minimization

During the discussion, participants shared their efforts to minimize waste generation, thereby reducing the amount of waste that ends up in landfills. One community member mentioned how they transformed their lifestyle to cut down on waste production. Initially, they faced significant food waste due to their busy schedules, leading to excess packaging waste. To address this, they adopted practices like hydroponic produce cultivation and purchasing a deep freezer to stock locally sourced meats they regularly consume, all with the goal of reducing food waste in their households. Another participant emphasized that it all begins with households developing awareness of the importance of taking action, such as reusing items and being mindful of excessive packaging, as a crucial step in waste reduction. In addition to the general public, producers must also bear the responsibility for waste reduction. People shared their viewpoints on this specific matter.

> *"As residents and citizens, we do so much…manufacturers have to do their part in making things durable, and repairable…A lot of times it's cheaper or more affordable to buy something new than to repair it…"* - (Community Member).

Some participants expressed skepticism regarding the principles of the circular economy, particularly in the context of plastic product production. They question whether the emphasis on "reduce, reuse, remake, and recycle" adequately addresses the environmental challenges posed by plastics. Instead, a more effective approach might involve a substantial reduction in plastic production itself rather than relying on circular economy principles as a justification for continued plastic production. Some participants referred to the term "closing the tap" in plastic production, which implies a proactive and comprehensive approach to reducing or halting the generation of new plastic products, thus curbing plastic production at its source. This term underscores the need for measures that go beyond recycling and reusing plastics and focusing on minimizing their initial production, which is essential for addressing plastic pollution and environmental sustainability.

3.3.1.1.2. Waste Diversion

Although individuals are passionate about recycling, they want the government to make the entire recycling process more transparent to the public. Some individuals have highlighted that in developed nations, there is a concerning trend in which governments divert waste to third-world countries, effectively adopting an "out of sight, out of mind" approach. During the summer, when a city strike occurred in the Mount Pearl area, household waste services were notably impacted, particularly for those without vehicles. Services were reduced to bi-weekly trash pick-up only. Furthermore, concerns arose about the potential increase in rat activity and additional garbage accumulation in the vicinity of Galway, a new development area. Over the past two years, there has been an observed rise in rat populations. Additionally, it should be noted that bulk garbage collection, which used to occur twice a year, was reduced to an annual event. From a municipal perspective, events like the Mount Pearl strike have highlighted that waste management services tend to be among the first to face cuts, downgrades, or extended intervals between services when resources and budgets become scarce. Some community members hope that municipalities and non-profit organizations will make more extensive use of grants to address these issues.

Community members showed significant concerns about the ultimate destination of the materials sent for recycling. There should clearly be a stronger focus on reduction and reuse practices to minimize the volume of waste ending up in landfills. Municipal authorities provided insights into some of the prevailing challenges within the waste-handling process.

> *"Resident buy-in and implementation. Cost is a huge factor for municipalities. The tonnage fee is very high. No compost collection at this point. Only 2 streams (paper and plastic). Compostable material contributes to the tonnage and increased fee"* - (Town councilor).

As highlighted by a town manager, the geographical location at the northern tip of the peninsula presents the most significant challenge. With a small and widely dispersed population, the primary issue revolves around the collection and transportation of waste materials to a recycling depot, making transportation the foremost obstacle they face.

3.3.1.1.3. Landfill Waste Load

Local authorities have expressed deep concerns about the escalating levels of waste generation, which have put considerable strain on landfills. According to one town manager, their community has been collaborating closely with the municipality and government authorities to address this issue. To streamline waste management efforts, they decided to consolidate two or three landfills in the region into one. Consequently, all the waste from the entire region is now being funneled into one facility, and there has been a rapid growth in the volume of waste coming in.

Electronic appliances, which are not truly designed for longevity and incur higher repair costs, often lead to the decision to simply purchase a replacement. As noted by a senior official at the waste management facility, "*We are a wasteful society, where most items today are not repaired when they break. In my childhood, if holes appeared in my jeans, they were stitched by my mom*". To reduce the volume of wet/organic waste dumped in landfills, a few community members proposed the idea of community-based composting. This idea has garnered significant support among some members of the community. They argue that large-scale industrial composting encounters various challenges, whereas smaller, neighborhood-oriented composting programs offer substantial potential. The city currently lacks a system for collecting and managing organic waste. Research indicates that organic waste makes up approximately 30 to 40% of municipal solid waste. Therefore, as suggested by a community member, establishing a program for collecting organic waste, whether for composting or other purposes, would be a positive step toward reducing the volume of materials ending up in landfills.

3.3.2. Environmental Impacts of Waste Discharge

Historically, dumpsites operated with relatively few restrictions on the types of materials that could be disposed of, potentially leading to the ongoing leakage of hazardous substances into the environment from some of these older sites. Government officials have voiced apprehensions regarding the potential risks associated with these waste disposal sites.

> *Well, most concerns would be contamination of potable water supplies and soil and groundwater or surface water…persistent organic pollutants and heavy metals have been a problem in some cases, where old transformers were disposed of to landfill sites that were not regulated…-* (Senior environmental scientist, provincial government).

Certain concerns revolve around issues commonly associated with landfills, such as the presence of rodents and vermin. Additionally, according to a senior environmental official from the provincial government, there is ongoing apprehension about leachate from older, first-generation waste disposal sites, as its potential migration and impact on soil and water quality remain uncertain.

3.3.2.1. Subthemes -

3.3.2.1.1. Soil, Air and Groundwater Monitoring

Interviewees with environmental scientists and engineers highlighted the significance of environmental monitoring in the vicinity of waste disposal sites.

> *"Monitoring it from an air quality perspective is important…monitoring the soil for leaching of other contaminants that are going into the water table…having leachate from the waste sites getting into nearby brooks, streams or even springs"…* - (Environmental protection officer, provincial government).

The feasibility of such an approach would likely be contingent upon the specific geological characteristics of the area as well as the localized hydrogeological conditions in proximity to the site and any downstream areas. As suggested by a senior official from the regional health authority, it would be advisable to implement groundwater monitoring, particularly on sites affected by these factors. Participants discussed the various conditions that could potentially result in leachate runoff from waste disposal sites. They emphasized the importance of actively monitoring and addressing issues at older dump sites. The necessity for monitoring largely depends on the nature of the site and the materials being deposited there. For instance, a well-managed site like Robin Hood Bay may require less monitoring due to its efficient operation. On the other hand, it could be more critical to focus on monitoring in areas with traditional landfills where waste management practices may not be as rigorous or well-regulated. This perspective was shared by an environmental protection officer in Newfoundland.

3.3.2.1.2. Devaluation of Land & Property

Community members noted that landfills often smell bad, are unattractive, and attract rodents and bugs. Together, they lower the value of adjoining land and property. Regarding any form of disposal area or landfill facility, the immediate concern often revolves around the "not in my backyard" sentiment. Issues such as unpleasant odors in the vicinity of one's property and the presence of rat infestations tend to accompany such facilities, and these factors influence the perceived risk of the devaluation of properties.

> *"I once owned a property on Logy Bay Road, which happened to be in close proximity to the original landfill site. The regional authority undertook several renovations and upgrades to the landfill, and I observed a noticeable improvement in terms of reducing odors and unpleasant smells"* (Faculty member from Memorial University).

3.3.3. Influences of Dumpsite Runoffs in Ocean Ecosystems

Community members engaged in discussions about the potential for contamination originating from dumpsites to find its way into nearby water bodies and streams, with the potential to ultimately affect the delicate ocean ecosystem.

> *"I think of the 'garbage forest' on the East Coast Trail, just across from the dump…I also think of places where my parents live (Ocean Pond, Deer Park) and other rural areas where there are absolutely no services outside of basic trash pick-up. You can go deep into the woods/ trails, in those areas, only to stumble upon old couches, mattresses or burnt-out RVs near ponds, which can't be good for the surrounding water bodies and animals…"* - (Community Member).

According to some community members, Robin Hood Bay sits directly along the coastline, and around 25 years ago waste disposal practices at this site were notably dissimilar. During that time, individuals would drive in, simply open their car doors, and dispose of their waste, which included items potentially containing hazardous chemicals like refrigerators or batteries. There was a distinct absence of efforts to control or manage the waste to prevent it from infiltrating the landfill. Consequently, as reported by a concerned community member, the Robin Hood Bay landfill now bears the burden of containing a substantial volume of toxic chemicals that are seeping into the surrounding water. Municipal authorities expressed significant apprehension regarding the improper disposal of waste into water bodies and wooded areas. Instances of materials being discarded in and around towns, specifically along riverbanks, within wooded regions, and along roadways, have come to their attention. This behavior has led to adverse consequences, including the degradation of bogs and marshes, harm inflicted upon wildlife, and the generation of unsightly surroundings. Notably, as highlighted by a town councilor, it has been observed that these materials do not undergo natural decomposition, as they persist in their deposited locations indefinitely.

Despite the presence of appropriate liners and leachate management systems in currently operational landfills, waste management officials have expressed concerns about the potential for plastic waste to be carried by the wind and end up in the oceans, given the proximity of landfill sites to coastal areas. Methane can be generated by landfills employing modern landfilling techniques, and concerted efforts are made to implement collection systems to capture it to the greatest extent possible. Additionally, it is recognized that leachate is produced as water passes through landfills, and without adequate controls it could indeed have adverse impacts. Furthermore, lightweight materials such as plastics and Styrofoam have the capability to disperse and potentially affect nearby lands, underground aquifers, and oceanic environments. These concerns have been emphasized by a senior official from a regional waste management facility.

The respondents have expressed concern regarding the presence of old, conventional dump sites across the province. They highlight the absence of adequate environmental data, which are essential for conducting studies on water contamination stemming from these historical sites.

> *"We have not had dumps in this province that were constructed in a deliberate fashion with a liner with any sort of containment…this is a province that has had very poor hydrological data…if there was a plume of contamination to even understand how it's affecting groundwater sources, we don't have data like that in many parts*" - (Senior official, Municipalities Newfoundland & Labrador).

Throughout the province, particularly in Labrador, there are locations where groundwater and bays have been contaminated by past military installations. Various substances, including PCBs and other materials commonly associated with military operations, were left in these areas. In Labrador, as mentioned by a senior official from a regional health authority, there have been several instances where old military dump sites have had an impact on the adjacent bays.

3.3.4. Concerns about Human Health and Seafood Contamination

When inquired about the potential for seafood contamination arising from landfills or other unregulated waste disposal sites, respondents indicated that the extent of contamination depends on the design of the landfills. While acknowledging the potential impact of leachate runoffs on aquatic species, they expressed the difficulty in conclusively attributing contamination to landfills.

The respondents also noted that a majority of landfills have been closed, and the ones still operational are second-generation landfills equipped with various leachate control measures and monitoring systems. Nevertheless, it was observed that fish species are relocating to different areas and returning, and invasive species are emerging. In light of these dynamics, the suggestion was made to conduct further studies, as proposed by a senior health official from the provincial government. Additionally, a landfill is recognized as a point source of pollution. Observations have revealed a conspicuous absence of a stable or enduring aquatic species population in the vicinity of such landfills. As expressed by a senior health official from the provincial government, "*while we acknowledge the potential risks associated with leachate runoff, comprehensively evaluating its intricate and far-reaching effects on aquatic life remains a daunting and complex challenge*". Health officials have been actively deliberating the issue of seafood contamination, particularly with heavy metals and other harmful toxins. Such contamination can potentially render seafood unsafe for consumption, prompting serious safety concerns. *"I would say obviously eating anything that's contaminated with any kind of pollutant can definitely have detrimental effects on somebody's health…microplastics being eaten by fish that we then consume…PCB contamination or any substance that bioaccumulates in the food chain has a potential to have negative impacts on human health for sure"* - (Senior official, regional health authority).

A community member also expressed concern about the garbage being dumped in the oceans and their reluctance to eat fish. The individual finds this situation concerning, particularly due to uncertainty regarding what is being dumped by corporations. Their primary concern centers around the activities of commercial enterprises. Worries were expressed about the oceans and water quality and the substances being dumped into them. Consequently, they suggest that if they had a child, the recommendation might be to avoid fish consumption.

3.3.4.1. Subthemes -

3.3.4.1.1. Propensity of landfills to contaminate seafood

When asked about their seafood consumption, the majority of community members responded that they eat seafood that is locally available. Participants emphasize the importance of adopting a local diet. Consequently, they make a conscious effort to include a substantial amount of fish and seafood in their meals. Mussels, which are known for their high iron content, are a particular favorite, but they also have an appreciation for cod, small shrimp, and tiny scallops. In summary, fish constitutes a significant portion of their regular diet.

Participants expressed a shared concern regarding the potential contamination of their seafood supply and the potential impact of leachate runoffs into freshwater sources on local fisheries. Within this context, a community member and their family consistently consume fish they catch themselves. They expressed significant worries regarding the likelihood of mercury contamination stemming from Robin Hood Bay making its way into the water.

> "*In this province, agriculture and fisheries represent a highly significant portion of the economy. It is believed that landfill leachate would not directly access the ocean. If such an occurrence were to transpire, it would likely involve a freshwater source. Nevertheless, if it were to happen, it is asserted that it would undoubtedly pose a substantial threat to fisheries"* (community member).

Several individuals expressed uncertainty regarding the sources of their seafood and concerns about the safety of fishing areas. In the case of one community member and their family, salmon is a regular catch, occurring approximately once a week. They rely on government oversight to verify the origins of the seafood they consume; however, both cod and salmon's origins remain uncertain. Additionally, a community member's spouse, who hails from central Newfoundland, has a strong passion for fishing in areas traditionally considered safe. Nevertheless, upon reflection, concerns have arisen about the long-distance transport of contaminants and pollutants that ultimately find their way into the ocean. These shared uncertainties highlight the complexities and potential risks associated with seafood consumption and fishing practices.

The respondents highlighted concerns regarding the potential contamination of local fish by landfill leachate. They pointed to studies conducted in other countries and recalled a previous incident of polychlorinated-biphenyl contamination in a local trout farm within the province, underlining the possibility of similar issues affecting their region. An environmental protection officer from the provincial government recently came across an article discussing the detection of carbon fiber particles in Japan, China, and other Asian regions. These particles were found in the skin and skeletal components of fish. Drawing from this information and the scientific evidence observed in different parts of the world, the officer believes it is highly plausible that similar phenomena might be occurring in their local area.

3.3.4.1.2. Potential impacts on human health

The officials discussed the potential impact of eating contaminated food on human health in general. It is believed by an environmental protection officer from the provincial government that the stomach, while effective at breaking down foods, encounters challenges when it comes to breaking down various chemicals and other substances that may originate from leachate. Consequently, the consumption of contaminated food is thought to have the potential to affect one's health in numerous ways that extend beyond the physical realm and possibly impact genetic factors and even future generations.

> *"The contaminants that we're seeing in many instances, of course, bioaccumulate, they work their way up the food chain…It can have a health impact, as direct and observable as indigestion or gastrointestinal diseases. On the other end of the spectrum, it can be*

something that's a much more ambient, multi-source, potential issue that results in cancer or other chronic diseases" - (Senior official, provincial government).

A community member cited the instance of lead contamination in downtown St. John's as a compelling example underscoring the importance of pilot studies in identifying environmental concerns. They further suggested that similar pilot studies could be beneficial for communities residing near landfill sites.

The community had not foreseen the presence of a lead issue in their downtown area until a member of the geography department, who had children living in the vicinity, raised concerns about the safety of allowing their child to play in the backyard soil. Subsequently, soil analysis was conducted, uncovering a significant lead problem. The community expressed gratitude for this discovery, which prompted them to discontinue the cultivation of any food crops in the soil due to safety concerns that emerged in light of these findings.

Interviewees, who included public health officials, stated the importance of monitoring the health of those who live close to waste disposal facilities. A senior health official from the provincial government mentioned that various parts of Canada and the United States conduct the monitoring of individuals residing in proximity to electrical and power lines due to concerns for their well-being. Drawing a parallel, the official emphasized the importance of similar vigilance in areas with landfills.

Health officials pointed out the possibility of downslope impacts of the dumpsite in the community and the role of primary health care in addressing this issue. The likelihood of individuals being affected downstream in the path of water flow was mentioned. In such a scenario, these individuals would not typically approach public health services unless their primary healthcare providers began to observe symptoms and health issues, including elevated blood levels, kidney and liver problems, and central nervous system complications, which could potentially be attributed to the impacts of contamination from waterbodies on these individuals. This perspective is shared by a senior official from the regional health authority.

The interviewees, who included public health officials and environmental scientists, were in consensus that it is imperative to implement health monitoring measures for workers who are regularly involved in garbage collection and waste handling. From an occupational health and safety standpoint, it is considered crucial to monitor workers at landfill sites for potential exposures, such as dust and landfill gases such as hydrogen sulfide. Therefore, according to a senior scientist from the provincial government, conducting annual health checks for landfill site workers is seen as a highly beneficial practice.

> *"I know speaking here at Robin Hood Bay, one of our regional facilities, they take their worker health safety very seriously…preventing any exposure to hazardous substances directly to their employees...maybe some spot checking for long term effects of unknown material exposures for sure would be beneficial"* - (Senior environmental protection official, provincial government).

3.3.5. Public Education/Awareness

The participants placed a strong emphasis on the importance of increasing public awareness and education regarding waste management issues. They also discussed the potential role that modern technology could play in enhancing waste management practices in the near future.

> *"I think it's just public education. I think we need to get into the school systems…public hearings, to have public input, doing surveys, whether that's hosting a public event or doing something through the social media everybody's now connected to help come up*

with a solution. We need to come together to solve the problem" - (town manager, a town in NL).

The significance of this matter particularly comes to the forefront when individuals are actively striving to reduce their carbon footprint. It is a shared responsibility that extends to municipalities as well. The importance of engaging in public consultation is emphasized as a crucial aspect of this collective effort. It is believed that every possible endeavor should be undertaken to foster public engagement and provide educational opportunities whenever they arise. This sentiment was eloquently expressed by a town councilor hailing from a city in Newfoundland, as they underlined their deep commitment to environmental awareness and community involvement.

3.3.6. Role of Modern Technology in Waste Management

When asked about the potential benefits of GIS and modern technology in waste management, the participants highlighted various applications, including the real-time tracking of landfills and other valuable uses.

> *"we use it [Geospatial technology] right now, mainly for identification of landfills, landfill locations and a lot of historical landfills that have been closed in this province for tracking purposes…to use some imaging technology to try to track the migration of any of that leachate, not something I have a whole lot experience in, but I guess there's a possibility there"* - (Senior environmental protection official, a city of NL).

Utilizing this technology can assist in pinpointing the proximity of nearby water bodies and tributaries and in creating hydrology flow maps. Regular data collection helps ensure that the boundaries of the landfill remain contained within a specific area to prevent any encroachment that might negatively impact sensitive habitats. As noted by a senior environmental official from a city in NL, the NL region is blessed with beautiful wildlife, and the land itself is expansive, rugged, and largely untouched.

3.4. Discussion

The study garnered the opinions of major stakeholders in waste management, including landfill managers, town mayors, recyclers, environmental scientists, and garbage collectors and community members, whose input is of paramount importance. Environmental scientists and recyclers provided insights into emerging technologies and best practices in waste management. Their opinions can drive the adoption of innovative solutions that enhance recycling, waste reduction, and sustainable practices. Town mayors, landfill managers and the general public provided insights into the specific needs and challenges of their communities. Their opinions could help tailor waste management strategies to suit local circumstances while taking into account factors such as population density, infrastructure availability, and cultural preferences. Involving a diverse range of stakeholders ensures a well-rounded and comprehensive approach to waste management. Each stakeholder group brought a unique perspective and expertise to the table. Landfill managers, recyclers, environmental scientists, and garbage collectors had firsthand experience and knowledge about the challenges and opportunities within waste management. Their insights are crucial for making informed decisions and developing effective strategies. Their inputs helped in identifying potential pitfalls, considering different viewpoints, and developing solutions that address various aspects of waste management, such as environmental impacts, technical feasibility, economic viability, and social implications.

Ineffective landfill management and waste transportation may harm the environment and public health. Handling and disposal methods may pollute air, water, and land. Improperly discarded or untreated waste can cause serious health problems in nearby communities. Toxic pollutants and POPs from waste leaks can pollute soil, water, and the air. The study by Triassi et al. (2015) found that landfilling causes underground water pollution from the leaching of organic, inorganic, and other substances of concern in waste; air pollution from particle suspension; odor pollution from municipal solid waste deposition; and marine pollution from potential run-offs, while nearby communities may be exposed to carcinogenic and non-carcinogenic underground water and gas pollutants.

Even though NL has state-of-the-art waste management facilities, this study found that the open dumping of waste has been practiced, especially in rural areas, due to a lack of transportation facilities to bring bulk waste such as furniture and mattresses to waste management facilities, as described by community members. In addition, community residents shared firsthand accounts of the open disposal of scrap metal, used paint cans, and other materials that have been frequently thrown in the woods. This information seems to be rather alarming. Although Waste Management emphasized the availability of better segregation and waste collection facilities, it has been observed that there is an absence of transparency in reference to public education and the understanding of waste diversion programs.

The province also needs to work on its most pervasive problem of food waste. At the disposal phase, numerous methods can be employed to prevent food waste. We can clean, repurpose, or recycle food packaging (where purchasing plastic is unavoidable), and we can compost food scraps to create rich soil for gardening while preventing a significant amount of food from ending up in landfills. For example, a modest project in a small city (Corner Brook) in western Newfoundland aims to make more people aware of how much food is wasted and how helpful it may be to practice composting. According to the provincial government, thirty percent of household waste is organic (Bird, 2021). Community members emphasized the need for small-scale community composting. Thus, local authorities must make efforts to improve community-level composting facilities for the management of organic waste.

During the interview, environmental scientists/protection officers and health officials emphasized the significance of frequently inspecting the soil, air, and groundwater around both closed and active waste disposal sites for potential contamination. As community members voiced concerns with the waste deposited in the oceans and their reluctance to consume fish, officials described how seafood can be polluted with heavy metals and other contaminants, making it unhealthy to consume. According to an ACAP report (Priddle, 2005) from December 2005 on an investigation of contaminant loadings from the Robin Hood Bay Sanitary Landfill, it was discovered that excessive levels of toxic ammonia and a severely depleted supply of dissolved oxygen were harmful to aquatic organisms inhabiting Skerries Brook (observations during sampling suggest that the stream may be devoid of aquatic life, possibly as a result of toxic leachate from the Robin Hood Bay landfill). Within the 1.6-km development exclusion zone, there were residential construction projects underway, and the landfill is less than 150 m from a water body (i.e., Skerries Brook). The report also highlighted the importance of monitoring water bodies and soil near waste disposal sites.

It is also noteworthy to mention here that over the years, Newfoundland has made tremendous strides in the recycling of electronic waste. Regulations mandating extended producer responsibility or product stewardship for designated electrical and electronic devices have been the predominant form of e-waste law in Canada (Schroeder, 2013). Extended producer responsibility aims to hold manufacturers accountable for the whole life cycle of their products, including the cost of recycling and disposal.

The Electronic Products Recycling Association (EPRA) oversees the province's e-waste recycling program, which aims to collect, process, and recycle electronic trash in an environmentally friendly and secure manner. The e-waste recycling program in the province accepts a variety of electronic items, such as televisions, computers, and cell phones. These goods are collected from numerous drop-off points throughout the province and transferred to processing facilities. In NL, as in many other locations, there are nonetheless still loopholes and obstacles in the recycling of electronic waste. The following are some prevalent concerns: Certain distant or rural parts of NL may not have easy access to e-waste recycling facilities, leading to the improper disposal or stockpiling of e-waste. Despite efforts to increase public awareness, some individuals may be unaware of the significance of e-waste recycling and the risks connected with inappropriate disposal. The enforcement of e-waste recycling legislation might be difficult in some regions, especially in distant or rural areas. In terms of the cost of repairing electronic products, while the EPRA manages the e-waste recycling program, financing for the program may not be adequate to fund continuous operations and expansion. As more and more electronics are incorporated into daily goods, the right of consumers to repair their own products becomes increasingly important. Goods that cannot be fixed, particularly "smart" products, contribute to resource depletion and climate change. New regulation is pressuring manufacturers to respect the right of consumers to repair their electronic devices (Byrne, 2021). Further education and awareness-raising campaigns, infrastructure improvements, and more financing to support e-waste recycling initiatives can address these obstacles.

Significant perception gaps between community people and waste management officials can lead to misunderstandings, mistrust, and ineffective waste management techniques. Since they are the ones who generate waste on a daily basis and are immediately affected by the collection, transportation, and disposal of waste, community members frequently have a more direct and personal relationship with waste management. They may be concerned with the frequency and dependability of waste collection, the cleanliness of public spaces, and the environmental and health impacts of waste disposal facilities. The elderly members of the community were concerned about the unregulated disposal of rubbish in the past and its potential impact on the environment. They also emphasized the significance of living more sustainably by routinely reusing old products.

Meanwhile, waste management officials may take a more technical and systemic approach, focusing on optimizing collection routes, minimizing expenses, and adhering to rules. They may also have access to data and knowledge that community members may not have easy access to.

It is imperative that waste management officials participate in transparent and open communication with community members, listen to their concerns and feedback, and include them in decision-making processes in order to bridge the perceived gap. This can help establish trust and improve comprehension, ultimately leading to more effective and sustainable waste management techniques that benefit both the community and the environment. Further research studies are needed to better understand any gaps and loopholes in waste management practices in the province through increased collaboration and support from policy makers and researchers. Public perception studies could help waste management authorities and policymakers understand how local communities perceive landfills and waste management practices. This insight is valuable for building trust and engaging communities in decision-making processes. When communities feel heard and informed, they are more likely to accept and support waste management initiatives. Opinions from stakeholders provide critical input for the development of waste management policies and regulations. These policies need to be well-informed, practical, and effective, and the expertise of stakeholders ensures that they are grounded in real-world considerations. Stakeholders such as environmental scientists and recyclers often have insights into public perceptions and behaviors related to waste management. By understanding these perspectives, authorities such as landfill managers, town mayors and decision makers can design more effective public engagement campaigns and communication strategies related to efficient waste management.

3.5. Conclusion

This study offers valuable insights into current household solid waste management practices in the province and the perceptions of the local population regarding waste management. Despite a genuine concern for the environment among most residents who participated in interviews, there remains a limited understanding of solid waste management within these communities. Several factors contribute to this lack of awareness, including a lack of transparency in public education and awareness initiatives, insufficient support from regional authorities, financial constraints, and a scarcity of solid waste transfer facilities. To address these challenges, there is a need to establish systems for collecting non-biodegradable bulk waste, such as unused furniture, electronic waste, and metals, from remote areas within the province. This proactive step can help improve waste management practices and environmental conservation efforts. In conclusion, involving major stakeholders in waste management decision-making can ensure a holistic, well-informed approach that takes into account various perspectives and areas of expertise. This can lead to more effective, efficient, and sustainable waste management practices that benefit communities, the environment, and the economy. Collaboration between different stakeholder groups promotes synergy and cooperation within the waste management system. Landfill managers, recyclers, environmental scientists, and others can work together to address complex challenges related to waste management that require multidisciplinary expertise.

Ethical Consideration: The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy.

Declaration of Competing Interest: The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Acknowledgments: The project has received funding from the Ocean Frontier Institute (Seed Fund) and the Natural Sciences and Engineering Research Council of Canada (CREATE fund).

Table 2 Themes and Sub-themes of transcribed interview data

Theme	Waste Management - As Public Perceive
Sub-theme	Waste Minimization
	Waste Diversion
	Landfill Waste Load
Theme	Environmental Impacts Of Waste Discharge
Sub-theme	Soil, Air, and Groundwater Monitoring
	Devaluation of Land & Property
Theme	Influences of Dumpsite runoffs in Ocean Ecosystems
Theme	Concerns about Human Health and Contaminated Seafood
Sub-theme	Propensity of landfill leachate to contaminate seafood
	Potential impacts on human health
Theme	Public Education/Awareness and Role of Modern technology in waste management

Sub-theme	Public Education/Awareness
	Role of Modern technology in waste management

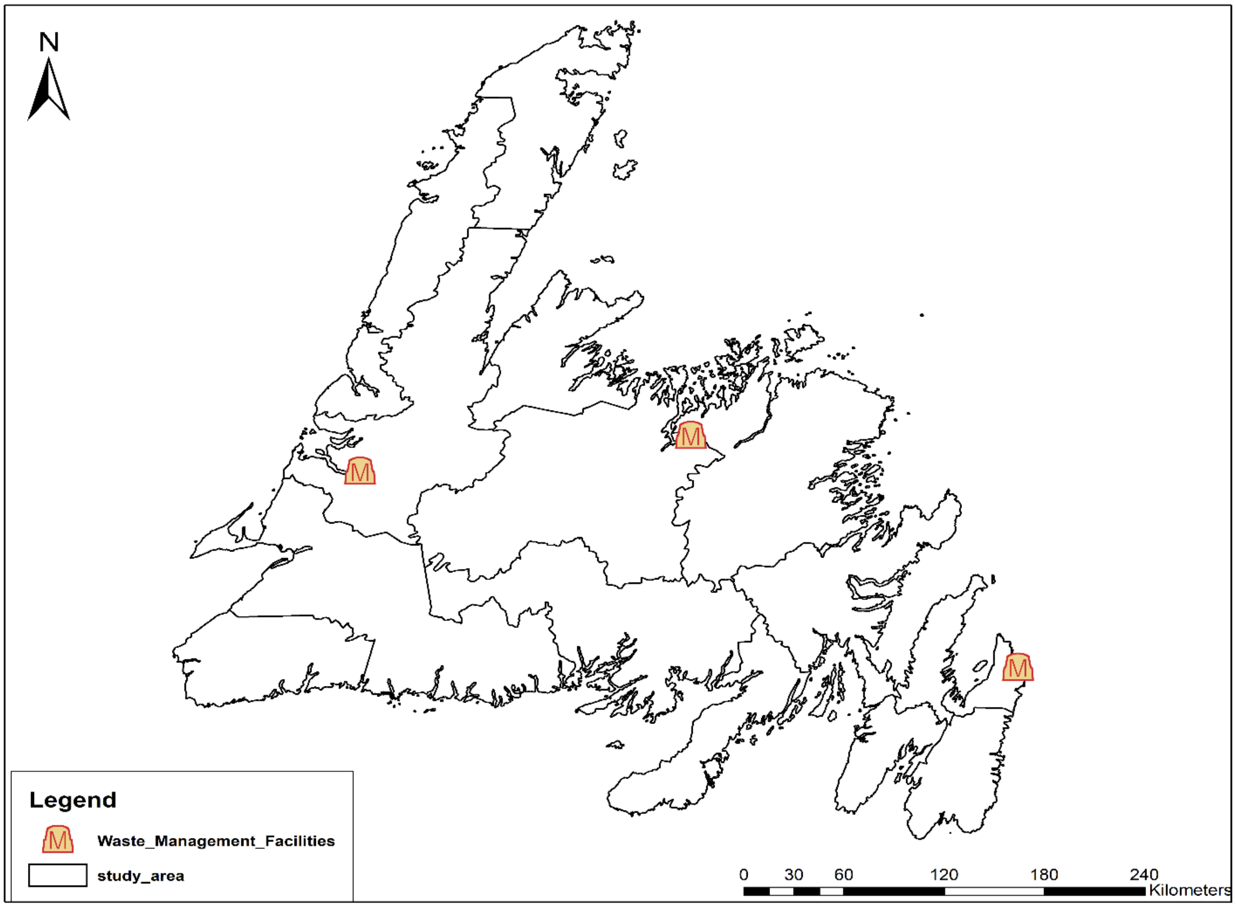

Figure 10 Study Area with Operational Waste Management Facilities (Source: Author)

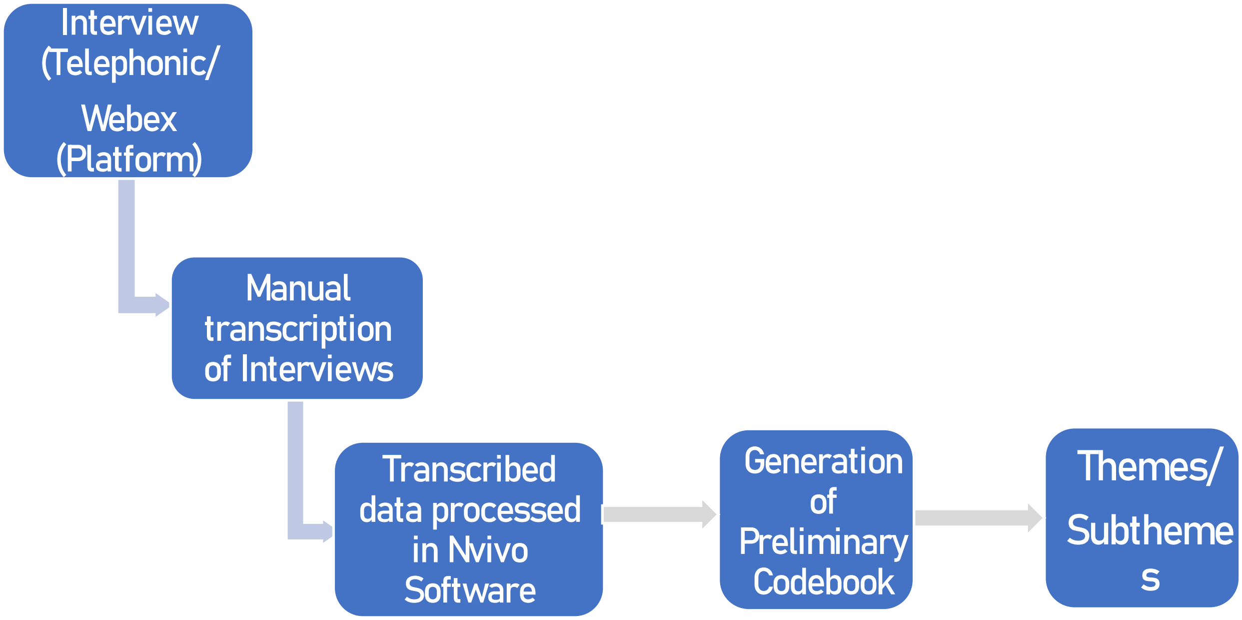

Figure 11 Flow chart of study design

Chapter 4: General Discussion & Conclusion, Limitations and Scope for Future Work

4.1. General Discussion & Conclusion

Waste disposal sites can have a significant impact on the health and well-being of ocean ecosystems as well as the surrounding communities Through a geographic analysis and investigation of public opinion, it may be possible to investigate the potential effects of waste disposal sites on marine ecosystems in other Canadian provinces as well.

Geospatial mapping helps assess the environmental impact of landfill sites by tracking their locations and evaluating their proximity to critical ecosystems, water bodies, and sensitive areas. This information is essential for ensuring that landfills are sited in areas where their impact on the environment can be minimized. It aids in the efficient management of resources and land use planning. Mapping landfill sites can help identify suitable areas for waste disposal, taking into account factors such as soil quality, geology, and accessibility, thereby optimizing land use. In addition to the geospatial analysis, a study of public perception helps to assess the level of awareness and concern among local residents about the potential impacts of waste disposal on the ocean ecosystem through surveys or focus groups to gather information about public attitudes, knowledge, and behaviors related to waste disposal and marine conservation. Landfills can have direct and indirect impacts on public health and well-being. A perception study can help identify health-related concerns and inform public health initiatives to mitigate potential risks. A perception study conducted periodically can track changes in public opinion and concerns over time. This longitudinal data can inform long-term planning for landfill operations and help operators adapt to evolving community expectations.

By combining these two approaches, it may be possible to identify potential areas of concern and inform the development of strategies for mitigating the impacts of waste disposal on the ocean ecosystem. For example, in this research study the results of the geospatial analysis were used to identify areas where some of the waste disposal sites are more or less vulnerable to the environment and may need to be relocated or modified or properly decommissioned, while the study of public perception could inform educational campaigns and outreach efforts aimed at promoting sustainable waste management practices and marine conservation.

Overall, exploring the potential impacts of waste disposal sites on the ocean ecosystem and public perception in Newfoundland, Canada, could provide valuable insights into the complex interactions between human activity and marine ecosystems and their impacts on ecosystems and human health as well as efforts to protect and preserve these critical resources for future generations.

4.2. **Limitations**

There was insufficient environmental data to perform a thorough geospatial analysis of the waste disposal sites and limited time for investigation and research given that it was a master's program.

4.3. **Scope for Future Work**

There is a need for more research in this study to conduct a more in-depth review of all closed and operational waste disposal sites in Newfoundland. This study would benefit from increased collaboration and assistance from policymakers and researchers to better identify provincial waste management gaps and loopholes.

collaboration and assistance from policymakers and researchers to better identify provincial waste management gaps and loopholes.

Ethical Consideration: The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy.

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APPENDICES

Appendix A: ICEHR Approval Letter

MEMORIAL UNIVERSITY

Interdisciplinary Committee on Ethics in Human Research (ICEHR)

St. John's, NL Canada A1C 5S7
Tel: 709 864-2561 icehr@mun.ca

www.mun.ca/research/ethics/humans/icehr

ICEHR Number:	**20222540-ME**
Approval Period:	June 6, 2022 – June 30, 2023
Funding Source:	OFI [RGCS# 20210996]
Responsible Faculty:	Dr. Atanu Sarkar Faculty of Medicine
Title of Project:	*Exploring the potential impacts of contamination ofocean coastal ecosystems by landfills in Newfoundland and Labrador: A GeospatialAnalysis and a study of public perception*
Amendment #:	***01***

July 22, 2022

Ms. Rashmi HazarikaFaculty of Medicine Memorial University

Dear Ms. Hazarika:

The Interdisciplinary Committee on Ethics in Human Research (ICEHR) has reviewed the proposed additions for the above referenced project, as outlined in your amendment request dated July 18, 2022. We are pleased to give approval to include government environmental engineers/scientists, as described in your request, provided all other previously approved protocols are followed. However, the relevant recruitment document and consent form should state that “government environmental engineers/scientists” are eligible to participate.

The TCPS2 requires that you strictly adhere to the protocol and documents as last reviewed by ICEHR. If you need to make any other additions and/or modifications during the conduct of the research, you must submit an Amendment Request with a description of these changes, for the Committee’s review of potential ethical issues, before they may be implemented. Submit a Personnel Change Form to add or remove project team members and/or research staff. Also, to inform ICEHR of any unanticipated occurrences, an Adverse Event Report must be submitted with an indication of how the unexpected event may affect the continuation of the project.

Your ethics clearance for this project expires **June 30, 2023**, before which time you must submit an Annual Update to ICEHR, as required by the *TCPS2*. If you plan to continue the project, you need to request renewalof your ethics clearance, and include a brief summary on the progress of your research. When the project no longer requires contact with human participants, is completed and/or terminated, you need to provide an annual update with a brief final summary, and your file will be closed.

All post-approval ICEHR event forms noted above must be submitted by selecting the *Applications: Post- Review* link on your Researcher Portal homepage.

The Committee would like to thank you for the update on your proposal and we wish you well with your research.

Yours
sincerely,

James Drover,
Ph.D.Vice-Chair,
ICEHR

APPENDIX B: RECRUITMENT DOCUMENT

Project Title: **A study of public perception to examine any potential impact of waste disposal sites in water bodies and ocean of Newfoundland.**

Researcher (Principal Investigator):
Rashmi Hazarika, Master's Candidate
Division of Community Health and Humanities
Memorial University of Newfoundland
Telephone: 709 986 7898
Email: rhazarika@mun.ca

Supervisor(s):

Dr. Atanu Sarkar (Associate Professor, Environmental and Occupational Health)

Division of Community Health and Humanities

Memorial University of Newfoundland

Telephone: 709 749 3590

Email: atanu.sarkar@med.mun.ca

Introduction:

I am Rashmi Hazarika, a graduate student of Community Health at Memorial University of Newfoundland. I am doing this study as part of my Master's thesis. I am conducting this research under the supervision of Dr. Atanu Sarkar.

Funding provided by: Ocean Frontier Institute Seed Fund; Natural Sciences and Engineering Research Council of Canada CREATE, Memorial University of Newfoundland.

Purpose of Study:

The proposed research aims to estimate any potential impact of landfill leachate runoffs into the waterbody and ocean coastal ecosystems in Newfoundland.

The study will look at public perception/opinion on probable environmental and health impact of landfills on waterbodies and the ocean ecosystem.

We have some questions to which we hope you will be able to share your experiences and provide us your views and opinions on the probable impact of landfills on waterbodies and ocean ecosystem of Newfoundland.

The study will help the policymakers in getting an insight of public perceptions on environmental impact of landfills into nearby waterbodies and ocean.

Who Can Take Part in the Research Study?

You may participate in the research if you are one of the following personnel of NL province:

- A community member.
- A town council-manager/clerk.
- A public health official.
- An Environmental scientist/engineer/Government Officials
- A garbage collector/landfill worker

What You Will Be Asked To Do:

You are invited to participate in a telephonic interview with Ms. Rashmi Hazarika. You will be asked a few questions on your views on waste disposal and the impact of landfills on waterbodies and the ocean. The interview will be recorded and analyzed later. If you say something you don't want recorded, you can let us know and we'll leave it out.

Length of Time:

The interview will take about 30 – 40 minutes of your time.

APPENDIX C: QUESSTIONNAIRE

Community Members:

1. What is your age? (You may prefer not to answer)

2. Which gender do you identify with?

- Male
- Female
- Other
- Prefer not to answer

3. What is your employment status?

- Full-time
- Part-time
- Contract/ Temporary
- Unemployed
- Unable to work
- Other
- Prefer not to answer

4. Where do you live? Please specify the name of your community.

5. How long have you been a resident of the community?

6. What services does your municipality provide for the separation of household waste?

7. In your opinion, what can be done to reduce waste generation so that it does not end up in landfills?

8. How important do you believe the term "Reduce” is in waste and landfill management?

9. How important do you believe the term "Reuse" is in waste and landfill management?

10. How important do you believe the term "Recycle" is in waste and landfill management?

11. How do you think improper disposal of waste in landfills could have an impact on the nearby water bodies and the ocean?

12. Do you and/or your family eat local seafood on a regular basis (fish, mussels, etc.)?

13. What are your thoughts on the possibility of landfills contaminating adjacent water bodies and the ocean, and how can this affect seafood consumption and health?

14. How important do you think it is to regularly monitor the health of people who live near the landfill/waste disposal site?

Town Councilor/ Managers/Waste Management Officials:

1. What waste disposal facilities does the local municipality provide to the community?

2. What are the current policies on landfills and waste management?

3. Do you have any waste diversion/recycling programs?

4. What are the common challenges in implementing a waste diversion/recycling program?

5. Where can the general public submit questions or concerns about waste management, and how will you effectively address the issues?

6. Do you believe improper waste disposal and landfill runoffs pose a threat to the water bodies and ocean, and if so, how?

7. What impact do you believe landfills have on our environment and human health?

8. What are your thoughts on the waste load in the current landfills? Is there a difference in waste generation compared to the past?

9. Do you think public perception is important for landfill site related planning and decision-making processes? What are the initiatives that can be taken in this respect?

Environmental Scientists/Environment Protection Officers/Health Officials/Provincial Government Officials:

1. What is the perceived risk of having a landfill site in close proximity to a community?

2. In your opinion, how essential it is to continuously monitor the air quality, soil and water nearby the landfill sites?

3. Do you think it's important to regularly monitor the health of people who live near the landfill/ waste disposal site?

4. Do you think it's important to regularly monitor the health of landfill site workers?

5.Do you think landfills/waste disposal sites could be a source of contamination in the water bodies and ocean ecosystems?

6.What are your thoughts on the possibility of local seafood being contaminated by leachate runoffs from landfills/waste disposal sites?

7.Do you believe that eating contaminated seafood can harm one's health? How?

8.Is there a public awareness and prevention program in place for seafood contamination and the health consequences?

9.What impact do you believe landfills will have on our environment and human health in the near future?

10.What are your thoughts on how geospatial technology can help with waste management?

Landfill Workers/Recyclers:

1. Please tell me about your work.

2. Do you believe that the disposal of household waste (unused furniture, carpets, etc.) is harmful to the environment?

3. What steps are being taken to manage discarded household waste in landfills?

4. In your opinion, is it essential to provide specialized training and equipment to emergency response personnel involved in waste handling?

5. How important is it for landfill workers to have knowledge of risk and waste management?

6. Do you think there is any health concern about having a landfill site in close proximity to the community?

7. Do you think it’s important to regularly monitor the health of landfill site workers?

8. In your opinion, could landfills/ waste disposal sites have an effect on the water bodies and ocean?