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Landfill Suitability Analysis using GIS (Geographic Information System) and AHP (Analytic Hierarchy Process): A case study of Scotts Bluff County, Nebraska

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The objective of this study was to identify and prioritize the potential sites that are the most suitable to host landfills using Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) in Scotts Bluff County, Nebraska. First, the criteria that influence in a decision-making process of landfill placement in social, environmental, and physical perspectives were established, and the area was assessed based on the grading structure of each criterion on a scale of 0 to 10. The second step was the main process for the study using the AHP. Thirty-two experts who work as planners, engineers, landfill staff, and environmental officials took part in a survey that consisted of making judgements regarding the importance of the criteria. The participants' judgement was used to calculate factor weight of each criterion using the AHP, and a final suitability map for the landfill was produced based on the weighted criteria. The excluded zones based on local and federal regulations were also applied to make the result more reflective of reality. Therefore, the final suitability result was described on a scale of 0 to 10 from the least suitable areas to the most suitable sites. Furthermore, the comparison between the map with the factor weights and without the factor weights was conducted to understand the importance of factor weight, and analysis of the factor weight by the participants' group and location was completed to understand the difference of value in relation to landfill.

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Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1. Problem Statement

Many municipal solid waste landfills have encountered potential problems such as environmental pollution and health risks in adjacent communities. A landfill often generates community complaints, resistance, and media reports, and an inappropriate landfill site may aggravate these situations while leading to negative public perceptions and attitudes in the community. In addition, urban sprawl, shortages of land sources, and increased waste have not only decreased the lifetime of existing landfills but also made locating new landfills difficult (Kontos, Komilis, & Halvadakis, 2003). The current trend toward larger and larger landfills makes finding or expanding landfill sites significant, which means a procedure for evaluating potential landfill sites is an inevitable step to deal with this controversial issue (Walsh & O'Leary, 2002). Thus, identifying the most suitable landfill sites is important to successfully operate the landfill and minimize further problems that might arise.

It is true that engineering improvements make siting a landfill easier and physically possible almost anywhere. However, sound technology such as synthetic geomembranes that may reduce landfill odors and other technical supports is not enough for potential sites to meet local regulatory requirements and public acceptance (Walsh & O'Leary, 2002). Besides, issues related to landfills are sometimes more than just a bad smell and blowing litter, which is directly connected to the community's quality of life. Thus, siting a landfill requires consideration of substantial evaluation criteria and multiple alternative solutions because it depends on different factors and regulations (Sener, Suzen, & Doyuran, 2006). Therefore, siting suitable areas for a landfill is a complex and multi-dimensional issue which needs diverse perspectives and an understanding of regional circumstances and variations.

There are over 2,000 active landfills in the U.S., and the average American throws out 4.4 pounds of trash a day (Peters, 2016). There were 22 permitted landfills in Nebraska as of 2019. Most of the household waste that is generated in Nebraska is disposed of at landfills and over two million tons of waste is sent to the state's 22 permitted landfills every year (United States Environmental Protection Agency, n.d.). According to the Environmental Protection Agency (EPA), states play a lead role in ensuring the federal criteria for operating municipal solid waste and industrial waste landfills regulations are met, and they may set more stringent requirements regarding location restrictions, composite liners requirements, leachate collection and removal systems, and operating practices (United States Environmental Protection Agency, n.d.). For instance, location restrictions are outlined that landfills are built in suitable geological areas away from faults, wetlands, flood plains or other restricted areas (United States Environmental Protection Agency, n.d.). Accordingly, the Nebraska Department of Environmental Quality specifies in Title 132 – Integrated solid waste management requirements regarding locational, design, operational, closure, and post-closure criteria and asks for detailed applications for new solid waste disposal areas and lateral expansions of existing solid waste disposal areas.

However, the requirements do not include specific information about each criterion except for a few provisions, which are quite ambiguous while leaving it to the landfill owner or operator's discretion. For example, Ohio enacted a provision about specific setback for landfills such as stipulating a specific setback distance from national and state parks, wildlife areas, and recreation areas, and this can be found in Ohio Administrative Code Chapter 3745 (Ohio Environmental Protection Agency, 2020). In Wisconsin, regulations prohibit landfill sites from within 300 feet of a navigable stream and within 1,000 feet of a lake or pond (Walsh & O'Leary, 2002).

Therefore, creating more intuitive criteria and considerations would be the first step to minimize many environmental hazards and unsafe configurations in relation to landfills. Deciding the importance of each criterion based on all interested parties' involvement also needs to be conducted to adjust several steps. There is no single set of criteria and successful siting process that can be applied to all regions and sanitary facilities, but it is clear that intentional landfill siting and design can help eliminate negative impacts on a landfill's host community and environments.

1.2. Research Objectives and Questions

The first objective of this study is determining social, environmental, and physical factors that have an influence when evaluating potential sanitary landfill sites. The requirements of government regulations, community acceptance, financial efficiency, public health, and minimization of environmental damage to natural resources are the primary conflicting values in the evaluating process. Identifying the factors is becoming more complex because of growing environmental awareness, as well as political and social opposition (Sener, Suzen, & Doyuran, 2006). Hence, the criteria should link with health and safety concerns and appropriate protection against the hazards associated with landfill construction and operation in order to identify the best available disposal location (Gardner, 2018). Therefore, environmental and health risks, economic issues, political issues, and social issues, such as future land use, should be contemplated as major siting considerations. Developing specific and concrete criteria will help narrow potential sites to a small number (Stinnett, 1996).

The second objective is comparing the difference among the importance of each criterion by people who are involved in the process. Not all criteria can be equally applied in the landfill siting process, so it should be weighted based on each associated group's understanding (Stinnett, 1996). Planner, engineer, consultant, landfill owner or operator, as well as other government officials are the essential members when gathering opinions regarding the landfill siting issue. However, it is obvious that various approaches and perspectives related to the topic will be discussed among them. Therefore, it would be meaningful to analyze the results of the importance of each criterion to each group and see how it differs and why they thought so. Moreover, the results may differ by the location of where the participant lives and works. In other words, the importance of the criteria that influence the siting landfill process can follow a different pattern according to the locational characteristics based upon whether the possible landfill sites are in urban or rural areas. Thus, it could take longer to decide the weighted ranking of the criteria by coordinating opinions, but it is essential to involve all interested parties including solid waste managers, planners, and even residents throughout the entire landfill siting process.

The last objective is deriving a final suitable area based upon all of the criteria, each with individual weights. The fundamental aim of the study is finding the most suitable area for a landfill in the study area, so identifying the few candidate sites will be part of the process. Additionally, final suitable areas will be compared, based on the weighted criteria that are determined by the AHP methodology. This comparison will illustrate the importance of the weights attached to each criterion.

In summary, this study identifies and prioritizes the potential landfill sites using Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) in Scotts Bluff County, Nebraska. This study will reinforce the process of deciding the importance of the evaluation criteria by getting the opinions from related experts, and the suitable sites in the study area will be identified by accomplishing the three objectives. The research questions will be tested in this study with the proper methodologies. Therefore, the research questions are as follows:

I. What kinds of criteria should be considered when evaluating landfill sites?

II. What does each expert group think about the importance of the criteria and how do these opinions differ? Is there a difference between the judgement of the importance of the criteria from people who live/work in an urban area and from a rural area?

III. Where would the suitable landfill sites be in the study areas? Is there a difference between the final suitable landfill sites that applied the weights of each criterion as compared to when equal weights are applied to each criterion?

Incorrectly planning where the potential locations for a landfill are can lead to lower public acceptance, and, consequently, it will make waste technical investigations and investments difficult. On the other hand, when the initial process of siting proceeds properly, it would be helpful for efficiency of operation and the future development of landfills in a sustainable perspective.

Chapter 2 Literature Review

2.1. Importance of landfill siting issue

Successful landfill siting and the effective management of municipal solid waste is very challenging for local authorities, planners, and engineers due to rapid industrialization, growing populations, different community characteristics, and land scarcity (Chen, Yu, & Khan, 2010). Public health concerns and risks for landfill construction are also the main difficulties to overcome (Kao & Lin, 1996). These potential issues are not only leading to the generation of a huge quantity of solid waste but also contribute to inappropriate dumping of waste which is now one of the key environmental challenges faced by humans (Gbanie, Tengbe, Momoh, Medo, & Kabba, 2013). Thus, a proper landfill siting process based on an examination of all the above issues needs to be developed. The siting process also needs to be environmentally and geologically sensitive, as well as economically and socially acceptable to the community (Baban & Flannagan, 1998).

The reason that landfill siting is regarded as one of the controversial issues is associated with community complaints and opposition toward landfills (Pol, Masso, Castrechini, Bonet, & Vidal, 2006). A landfill siting process usually leads to the NIMBY (Not-In-My-Backyard) phenomenon because of its physical impacts such as odor, noise, and blowing litter. Some studies (Zeiss, 1988) (Furuseth & O'Callaghan, 1991) have shown that a variety of factors related to environment, health and safety, and aesthetics would contribute to the process of creating residents' beliefs about the landfill, and the physical impacts and preconceived perceptions about the landfill mainly form the residents' beliefs about the landfill. Thus, siting a landfill should be considered more than simply deciding the location of waste facilities, because the process of siting a landfill is a process that occurs amid a complex of geographic, cognitive, affective, and political responses (Kraft & Clary, 1991).

2.2. Relevant Regulations and Requirements in Nebraska

In the United States, landfill siting guidelines have been developed by each state, but they are oriented based on Environmental Protection Agency (EPA) guidelines and requirements regarding landfill locational, design, and operational criteria. According to Nebraska Administrative Code, Title 132 – Integrated Solid Waste Management Regulations, Chapter 3, there are specific locational criteria for new solid waste disposal areas and lateral expansions of existing solid waste disposal areas. Exclusionary siting factors for Subtitle D landfills include airports, floodplains, wetlands, fault areas, seismic impact zones and unstable areas. Current and anticipated incompatible land use and lack of transportation access are also included as other exclusionary siting factors. Thus, all facility types including municipal solid waste disposal, construction and demolition waste disposal, fossil fuel combustion ash disposal, and industrial and delisted waste disposal shall be located in accordance with the standards as described in the sections of the regulations.

It is defined that a solid waste disposal area shall not be located in an area where the Nebraska Department of Environmental Quality finds that the solid waste activities will have a detrimental effect on the waters of the state including ground water elevation local aquifers, surface waters, and initial quality of water resources (Nebraska Department of Environmental Quality, 2016). Surface water formation and groundwater conditions will be highly impacted by landfill leachate collection and liner system, so hydrologic setting such as drainage, depth to groundwater can be used to further define suitable areas for a landfill (Walsh & O'Leary, 2002).

Nebraska Department of Environmental Quality (2016) has limited the area with the specific distance buffer zone from airport runway (10,000 feet) and the nearest edge of an existing right-of-way of any state, interstate or federal highway (1,000 feet). Additionally, they specify that it is forbidden to locate sanitary landfills not only within the areas of floodplains and wetlands but also unstable areas, fault area, and seismic impact zones. For example, Patrick and Philip (2002) emphasized that the areas with poor foundation conditions are not appropriate to construct a landfill because siting a landfill over a permeable formation such as gravel, sand, or fractured bedrock can pose a significant threat to groundwater quality and damage to surrounding circumstances.

However, it is stated that land use and population density of the proposed facility and of the area surrounding the facility within one mile of the facility boundaries should be described in the application, which means that concrete regulations regarding the social impacts such as the distance between the facility and the populated places do not exist. It is understandable that locational criteria regulations leave some aspects to landfill owners or operators because the landfill siting process significantly depends on local and community contexts. This can successfully provide the physical requirements but, unfortunately, it gives very little indication of the preferred conditions regarding landfills (Walsh & O'Leary, 2002). Hence, regulatory standards and requirements may be primarily incorporated when landfill siting process is progressed.

Therefore, the primary step for the study was applying the exclusionary criteria for defining unsuitable and suitable areas based on federal, state and local regulations as a starting point. The factors are stated in Title 132 – Integrated Solid Waste Management Regulations – including airports, floodplains, wetlands, fault areas, seismic impact zones and unstable areas (Nebraska Department of Environmental Quality, 2016).

2.3. Evaluating factors

There would be various elements that can be regarded as an essential factor to consider when siting a landfill in the community, and social, environmental, economic, and physical factors will be primarily considered. For example, New Jersey defined the factors such as geological, physiographical, hydrological, transportation, human environment, and resource conditions that are both desirable and unacceptable standards when siting a landfill and they are rigorously enforced factors (Clapham, 1990). Oweis and Khera (1990) have demonstrated that landfill site selection must be based on physical, safety, environmental, political and technical constraints. William N. Lane (1983) stated that it involves evaluating the basic suitability of all available land for landfills as an aid in the selection of a limited number of sites for more detailed evaluation. Thus, categorizing the essential factors varies by studies and factors may depend on local and regional conditions and circumstances. However, it is absolute that there are commonly considered factors such as distance from residential areas, road networks, and distance from surface water and groundwater resources that should be contemplated together.

Dividing considered factors in several categories depends on studies' objective and research questions. For instance, Salah Sadek (2006) grouped the criteria associated with landfill siting into three main categories: engineering and infrastructure, environmental, and socio-cultural and economical while Wang Guiqin (2008) categorized the factors into two groups that are environment factors and economic factors.

Environmental impacts such as air pollution, soil and water contamination and climate change caused by the improper placement of waste facilities are important situations which require that we look at what is happening (Kamdar, Ali, Bennui, Techato, & Jutidamrongphan, 2019). Thus, environmental factors are the most crucial components because the landfill may affect the biophysical environment and the ecology of the surrounding area (Siddiqui, Everett, & Vieux, 1996) (Erkut & Moran, 1991).

Economic factors must be considered in the siting of landfills, which include the costs associated with acquisition, development, and operation of the site (Erkut & Moran, 1991). This includes the facility's effect on property values, the construction and operating costs, and its impact on local industry (Stinnett, 1996).

Lober (1995) pointed out the fact that social and political opposition to landfill siting has been indicated as the greatest obstacle for successfully locating waste disposal facilities. Accordingly, equity in site choice, proximity to residential areas, the effect on community image, aesthetics and alternative and future land uses could be developed from the social perspective. Moreover, local elections, community groups' vested interests, site management responsibility and local control can be counted as political aspects that have an impact on the landfill siting process (Stinnett, 1996). Furthermore, Baban and Flannagan (2010) mentioned that landscape, agricultural land classification, risk assessment, and the chemical and physical nature of waste are recognized when trying to find an area suitable for the landfill purpose.

Overall, evaluating criteria was provided through detailed literature review, site-specific characteristics, and guidelines and regulations of local government on landfill site selection. Therefore, identifying factors that influence landfill siting in a variety of perspectives such as social and environmental will be the most significant stage to get better results in this process.

2.4. GIS-AHP application

Several techniques for landfills siting can be found in the literature and a GIS-based methodology is extensively used to facilitate site-selection studies because of its efficiency to manipulate and present spatial data. Due to their ability to manage large volumes of spatial information from various resources, GIS are ideal for site selection studies (Kao & Lin, 1996). Various types of multi-criteria decision making (MCDM) such as Analytic Hierarchy Process (AHP) are well-known techniques for resolving complex decision-making problems and it was developed by Saaty in 1970s (Saaty, Decision making with the analytic hierarchy process, 2008). Erkut and Moran (1991) demonstrated that a complex problem can be divided into a number of simple problems in the form of a decision hierarchy by using this method. Accordingly, these two techniques are often combined as a powerful tool to solve the landfill site selection problem (Khan & Faisal, 2008) (Charusiri & Ladachart, 2008) (Demesouka, Vavatsikos, & Anagnostopoulos, 2013).

Siddiqui and Everett (1996) indicated that Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) decision-making procedure can be used to exclude and rank the areas to aid in preliminary site selection. Randazzo (2018) conducted the research to test a methodology based on the application of Analytic Hierarchy Process and Geographic Information System in order to obtain a map of areas suitable for landfill establishment in Sicily, Italy. Kontos (2003) presented a methodology that consists of a GIS-based spatial analysis using 10 criteria. The method excludes unsuitable areas for any waste disposal activity and further assesses possible sites by using 19 criteria that have predefined weight coefficients on a 0 to 10 scale.

The GIS-AHP application method is not the only method used for siting and identifying potential areas for sanitary disposal sites. Guo and Zhao (2015) used the fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) approach that is one of the popular Multi-Criteria Decision Making (MCDM) methods to select the suitable locations of electric vehicle charging stations. It is also applied to prioritize the potential ecotourism sites in Surat Thani Province, Thailand. Using a semiquantitative GIS-based Analytic Hierarchy Process approach, watershed vulnerability was assessed for Bernalillo County, New Mexico (Richardson & Amankwatia, 2018). Thus, various techniques were used by different experts and researchers with a variety of applications.

As discussed above, much research has been conducted over the past years on solid waste management and the siting process. However, very few studies brought out integrating factors including social, environmental, and economic factors as the evaluating criteria. Moreover, most of the related studies have internally assessed the importance of the criteria to use it as a weight and ranked them without analysis. None of the studies have compared the differences among the different associated groups that are interested in siting landfill process. Thus, this study focuses on identifying the factors that highly influence the landfill siting stage and examining how different associated groups rank each criterion based on their experience and background. This study also reclassifies the grading value of each criterion based on the study area characteristics and previous studies. Furthermore, this study will discuss possible topics regarding landfills in a planning perspective. Even though landfill siting issues are mainly argued with an engineering perspective, planners have an essential role not only in the decision-making process but also in considering and evaluating the related factors and components.

Chapter 3 Data and Methodology

3.1. Study Area

This paper will describe the results of the determination of suitable landfill sites in Scott Bluffs County, Nebraska. Scotts Bluff County is in westernmost Nebraska, where the North Platte River enters the State, is occupied by the valley of the North Platte River and adjacent uplands (Wenzel, Cady, & Waite, 1946). The land area of Scotts Bluff County is 723 square miles. The county is bounded on the north by Sioux County, on the east by Morrill County, on the south by Banner County, and on the west by the State of Wyoming. Scotts Bluff County occupies an area where the High Plains have been deeply and extensively eroded. One of the geographical features of the county is the magnificent bluffs that tower above the river on the south side. Chimney Rock is the northeastern-most on one such salient over east of the county line; Castle Rock, Table Rock, and several other nearby prominences comprise a somewhat eroded salient. As of the 2020 United states Census, the population of the county was 36,123, its county seat is Gering, and its largest city is Scottsbluff with a population of almost 15,000. Nine communities are located along the river, three of which have populations of more than a thousand, Gering, Mitchell, and Scottsbluff (Wenzel, Cady, & Waite, 1946).

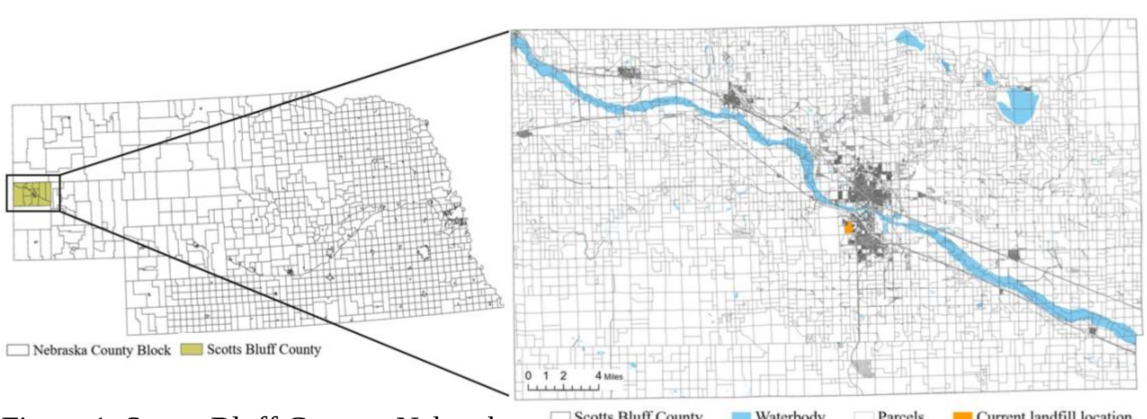
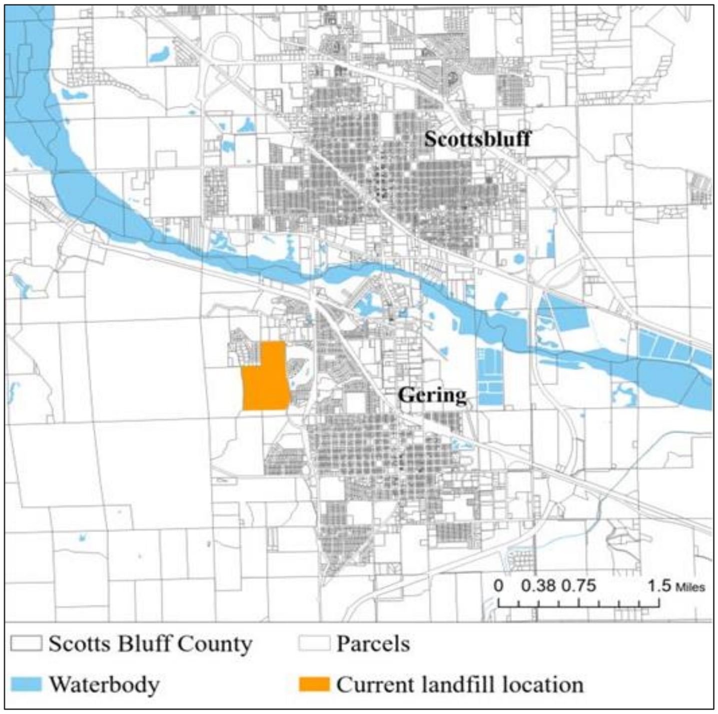


Figure 1. Scotts Bluff County, Nebraska

Figure 2.The city of Gering Landfill and the residential areas



The City of Gering Landfill is currently located at the center of the county as shown in figure 2. The start date of the landfill operation was uncertain, but the area was not planned to be developed as a landfill, according to the residents living in the community. It was originally a small dump site, but the residents did not think it mattered because they were expecting that it would be moved to somewhere else. The reason that they thought this was that the site is not only close to the residential areas but also next to the Scotts Bluff National Monument. Hence, the landfill has not only received a high number of complaints from the residents, compared to other landfills in Nebraska, but also experienced various problems in relation to the landfill. The situation with the Gering facility involves years of recorded community complaints. Because of the wind's effect during winter and spring, blowing litter from the landfill is one of the main problems. Also bugs and fly problems are increasing during the summer because of odors from the landfill. In 2015, methane levels began to creep up in the landfill, and more serious are environmental issues such as groundwater contamination and resident health risk (Purvis, 2018). Moreover, the landfill was approved a five-year extension to continue operating its municipal solid waste landfill in 2018, which lead to more complaint and conflict between the residents and the City because of the concerns such as coverage of landfill materials, blowing trash, methane accumulation in one of the landfill cells and improper disposal of accumulated water (Purvis, 2018).

Thus, the cites of Gering and Scottsbluff are currently looking to identify a land parcel located within a 45-mile radius of the Cities for their new landfill construction and it is an on-going project (Western Nebraska Regional Landfill: A community Project, 2019). During January 2018, the City approved a request for proposals for "engineering services for siting, development, permitting and design" of a new landfill (Purvis, 2018). Furthermore, they mentioned that they will do water testing to decide the permeability of the soil and how the water migrates around the city because storm water runoff from the Bald Peak area is one of the concerns. The City also currently asked staff to pursue an inter-agency agreement to oversee construction and management for a new regional landfill to accomplish their siting process and progress open discussion that needs to take place among the various communities (McCarthy, 2020). It means that the City wants to identify the most proper landfill location for the communities by redirecting their waste stream so that they can extend the life of the landfill and deal with the issues they encounter. One of the residents said that the cities including Gering and Scottsbluff need to perform due diligence and research on any proposed landfill sites (Purvis, 2018).

Therefore, this study will try to identify ideal locations based on key considerations including local and EPA landfill location requirements for a new landfill to serve Western Nebraska.

3.2. Methodology

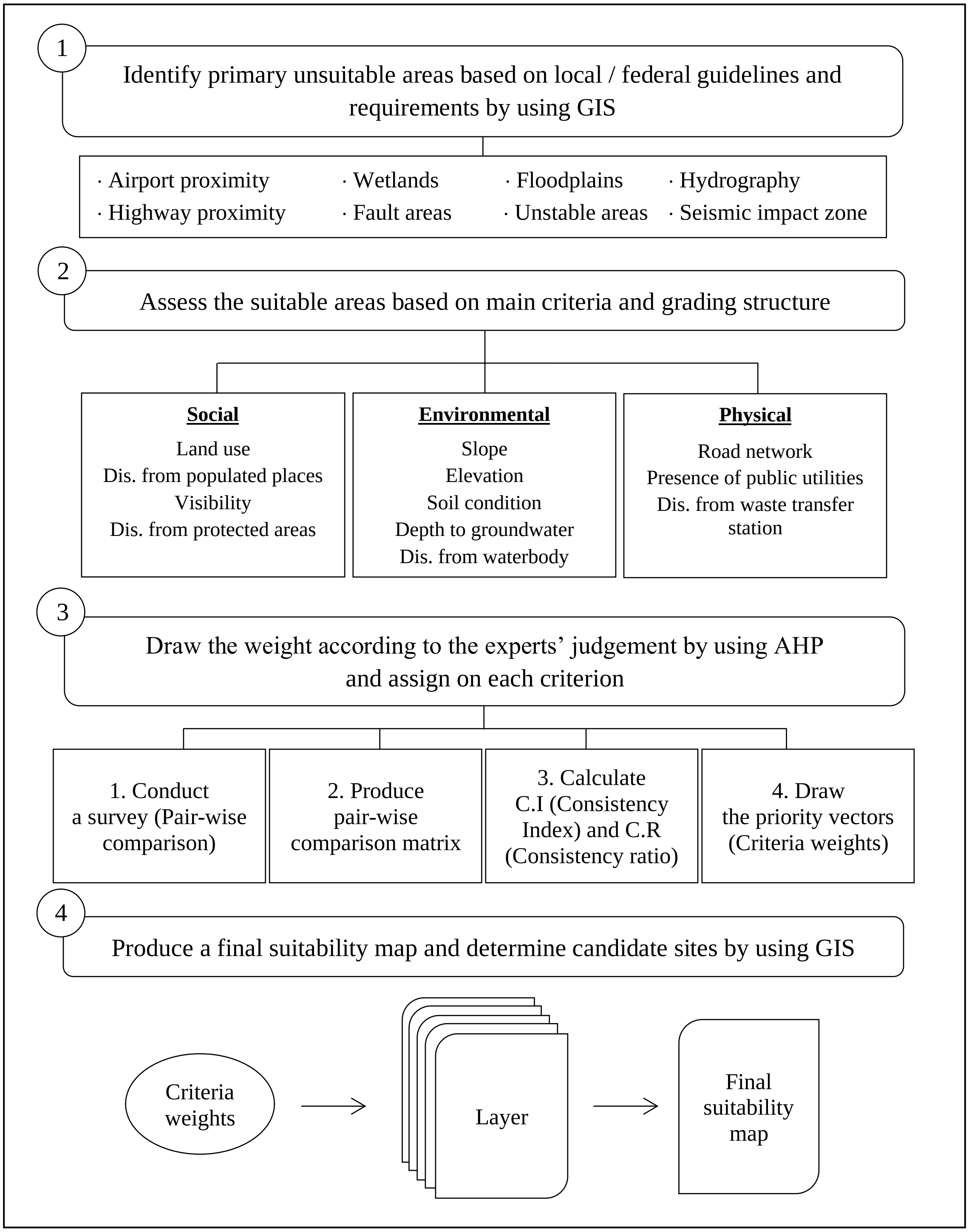


Figure 3. Flow chart of the methodology for landfill suitability analysis

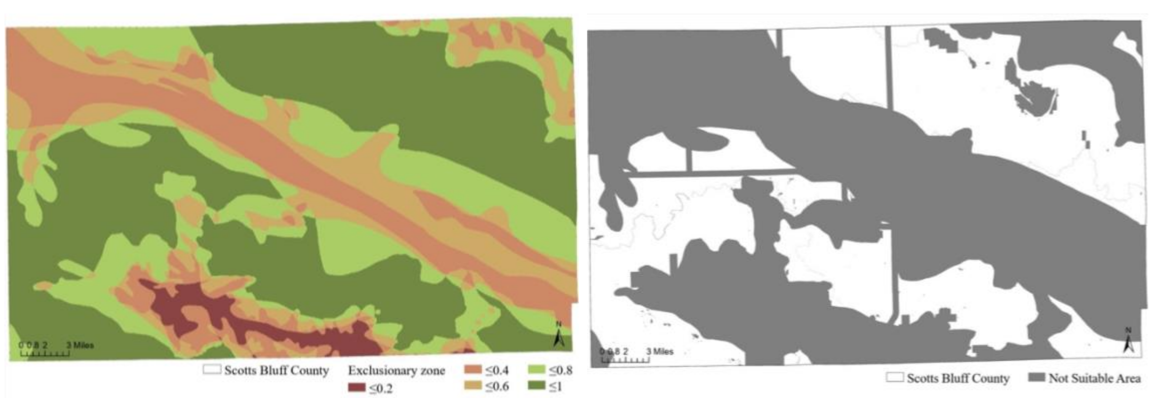
The main purpose of this study is identifying the most suitable sites within the study area. Thus, four essential steps were progressed to produce a landfill suitability map. The steps are as follows: (1) Identify the most unsuitable areas based on local / federal guidelines and requirements by using Geographic Information System (GIS) (2) Assess the suitable areas based on main criteria and grading structure (3) Draw the factor weight according to the experts' judgement by using Analytic Hierarchy Process (AHP) and assign on each criterion and (4) Produce a final suitability map and determine candidate sites by using GIS. Details of each step are described in Figure 3.

To be specific, first, priority suitable areas were considered to get the most suitable areas that satisfied solid waste landfill locational requirement by Environment Protection Agency and Nebraska Department of Environmental Quality by using GIS. As shown in table 1, 8 suitability criteria were used to exclude all unsuitable areas for any waste disposal facility in the study area. Each layer based on the criteria (table 1) was reclassified with the two index values that one represents all suitable areas and the other represents unsuitable for landfill siting. Suitable areas received 1 index value, while unsuitable areas received 0 index value, and the layers were combined by using the Raster calculator geoprocessing tool based on the same weight and exclusionary areas were applied by using the Union and Clip geoprocessing tools in GIS. As shown in figure 4 (a), five classes were created to express prior landfill suitability based on an equal interval classification method. Except the most suitable areas, which received a score over 0.8, the rest of the areas were regarded as an exclusionary zone for the landfill as seen in figure 4 (b). The result of this step will overlay on the map before producing a final suitability map at the last step.

Table 1. 8 evaluating criteria based on EPA and NDEQ regulations *(Nebraska Department of Environmental Quality, 2016)*

Category	Condition
Airport proximity	A new solid waste disposal area or lateral expansion shall avoid 10,000 feet of buffer zone on turbojet aircraft and 5,000 feet of buffer zone on piston-type aircraft.
Highway	No person shall locate a solid waste disposal area within one thousand (1,000) feet from the nearest edge of an existing right-of-way of any state, interstate or federal highway.
Water	A solid waste disposal area shall not be located in an area where the Department finds that the solid waste activities will have a detrimental effect on the waters of the state.
Floodplains	A new solid waste disposal area or lateral expansion shall not be located a 100-year flood plain.
Wetlands	A new solid waste disposal area or lateral expansion shall not be located in wetlands.
Fault areas	A new municipal solid waste disposal area or lateral expansion thereof, shall not be located within 200 feet (60 meters) of a fault that has had displacement in Holocene time.
Seismic impact zones	An owner or operator shall not locate a new municipal solid waste disposal area or lateral expansion thereof, in a seismic impact zone where the area with a ten percent or greater probability that the maximum horizontal acceleration in lithified earth material.
Unstable areas	A new municipal solid waste disposal area or lateral expansion shall not be located in an unstable area that includes poor foundation conditions, areas susceptible to mass movements, and Karst terranes.

Figure 4. Result maps of the first step



(a) Prior landfill suitability map

(b) Exclusionary zone for the landfill

The second step is the main task through the entire process of the study because the selection of appropriate evaluating criteria and establishing a grading value structure do have an important influence on the results. 12 evaluating criteria, 4 criteria for the social factor, 5 criteria for the environmental factor, and 3 criteria for the physical factor, were created based on various references and the community characteristics. Details of each criterion and references are discussed in the following Chapter 4 while the 12 criteria are listed in table 2 and the grading structure is described in table 3.

Table 2. 12 Evaluating Criteria

Social factor	**Environmental factor**	**Physical factor**
Distance from populated places	Slope	Road network
Visibility from urban area and street centerlines	Elevation	Presence of public utilities
Land use	Soil condition	Distance from waste transfer station
Distance from historic district and protected areas	Distance from surface water bodies	
	Depth to groundwater	

As depicted in table 3, the grading structure was deliberately determined based on the standards in the previous studies, references, and the community characteristics. Each criterion was assigned values from five to seven classes with scores between 0 and 10 in order to make the end results of the research have a range of scale from 0 (the least suitable) to 10 (the most suitable). The scale between 0 and 10 is a 1, 3, 5, 7, and 9 which correspond with the comparison scale in AHP, where 9 means very highly suitable, 7 means highly suitable, 5 means moderately suitable, 3 means lowly suitable, and so on down to 1, which means very low suitability. The areas that are assigned the grade of 0 are the constraint zones by local or federal government and related organizations regulations. For example, the areas, of river, lakes, and surface water were assigned a grade of 0, and 1, 3 ,5 ,7 ,9 grading points were assigned at a distance of every 0.5 km from surface water and groundwater sources. After creating the classes based on the grading structure for each criterion layer by using the Multiple ring buffer geoprocessing tool and the Reclassify tool, each layer was converted into individual raster maps.

Table 3. 12 Criteria and grading value structure

(a) Grading value structure of environmental criteria

Environmental Criteria					
Grading value	**Slope**	**Elevation**	**Soil condition**	**Distance from surface water bodies**	**Depth to Groundwater**
0			All hydric class; Very Frequent; 0.51 < K < 0.64	Area of rivers, lakes, surface water	0 – 3 m
1	S > 20°	E > 1400 m	Partially hydric (76-95%); Frequent; 0.41 < K < 0.50	d < 0.3 km	3 - 15 m
3	15°- 20°	1319 m - 1400 m	Common; Partially hydric (51-75%); 0.31 < K < 0.40	0.3 km - 0.8 km	15 – 25 m
5	10° - 15°	1255m - 1319 m	Partially hydric (26-50%); Occasional; 0.21 < K < 0.30	0.8 km - 1.3 km	25 – 35 m
7	5° - 10°	1206 - 1255 m	Partially hydric (1-25%); Rare; 0.11 < K < 0.20	1.3 km - 1.8 km	35 – 45 m
9	S < 5°	E < 1206 m	Not hydric; Very rare; 0 < K < 0.10	1.8 km - 2.3 km	d > 45 m
10				d > 2.3 km	

(b) Grading value structure of social criteria

Social Criteria				
Grading value	**Land use**	**Distance from populated places**	**Visibility from urban area and street centerlines**	**Historic district and protected area**
0	Protected land, Urban land, Roads, Open water	d < 0.5 km	Inside of urban area and street centerlines	Area of historic district and protected area
1	Forest and woodland	0.5 km - 2 km	< 0.5 km from urban area	d < 0.5 km
3	Other agricultural land, Summer fallow	2 km - 3.5 km	0.5 km - 1km from urban area	0.5 km - 1.5 km
5	Dryland, Irrigated land	3.5 km - 5 km	d < 0.3 km from street centerlines	1.5 km - 3 km
7	Pastures land, Grass land	5 km - 6.5 km	0.3 km - 1 km from street centerlines	3 km - 4.5 km
9	Barren	6.5 m < d < 8 km	d > 1 km from street centerlines and urban area	4.5 - 6 km
10		d > 8 km	No visual contact	d > 6 km

(c) Grading value structure of physical criteria

Physical Criteria (Infrastructure)			
Grading value	**Road network**	**Distance from waste transfer station**	**Presence of public utilities (Electricity, water)**
0	d < 0.3 km from state, interstate, and federal highway		d < 213 m (700 ft)
1	d > 5.3 km	d < 4 km from waste transfer station	
3	4.3 km - 5.3 km	4 km - 8 km	
5	3.3 km - 4.3 km	8 km - 12 km	
7	2.3 km - 3.3 km	12 km - 16 km	
9	1.3 km - 2.3 km	16 km - 20 km	
10	0.3 km - 1.3 km	d > 20 km	d > 213 m (700 ft)

The third step is the GIS-AHP application process for this study. AHP has an important role in this study to decide the weights of each criterion based on experts' judgement. It was developed by Saaty (1980) to support decision makers to arrive at the best decision in a case of multiple conflicting objectives. There are four steps to produce weight values for a suitability analysis based on the solution of an Eigen value problem (Kara & Doratli, 2012). The results of the pair-wise comparisons will be arranged in a matrix. The first normalized Eigen vector of the matrix will give the ratio scale, which is regarded as a weight, and the Eigen value will determine the consistency ratio (Goepel, 2018). Thus, the weight values would be calculated by using AHP and assigned to each criterion, then the weights were combined into a map in order to derive the final proper area for the landfill. The concrete steps are presented with the results as below:

AHP Step 1: Conducting a survey of pair-wise comparisons

Judgements of importance for each criterion is essential to start AHP methodology. Hence, experts who are related to the landfill issues and interested in this topic completed the pair-wise comparison survey for the 12 main criteria to determine weight value for each criterion in order to increase the validity of the study. The experts who participated in were randomly chosen and they are each currently working as a planner, engineer, landfill staff, landfill inspector, or consultant in the U.S. and they also have some background information in terms of landfills. The type of public sector planners that were included in the survey were Development View Planning Department, Long Range Planning Department, and Environmental Service Department. A Landfill inspector who belongs to the Department of Environmental Quality was also asked to complete the survey because they regularly visit the landfill sites, and directly hear and see the related issues. Responding engineers were members of SWANA (Solid Waste Association of North America) and interested in solid waste management. Moreover, several graduate students took part in the survey who are majoring in engineering and focusing on waste management systems and related materials. Landfill staff who currently own or are operating a landfill also responded to the survey to share their opinions. The geographic scope of experts whose views were consulted was not constrained, but experts who are currently working in Nebraska, especially Lincoln and Omaha, mainly participated in the survey.

The survey was conducted via email for about three weeks by providing a link for group input using AHP online system (Goepel, 2018). The introductory email and the contents of the survey are attached in the appendix. The research objective, method, and the description of the criteria were included in the email.

Total thirty-two participants took part in the survey, and they were asked to decide the importance of criteria and had to do 4 sets of pair-wise comparisons to complete the survey. It consisted of 3 levels of decision hierarchy, where the first level represented the main aim of the analysis which is the landfill suitability, the second level showed the three main categories of criteria which are social, environmental, and physical. The third level represented the 12 evaluating criteria for the different aspects in relation to landfill as seen in table 4. All criteria were compared in pairs and the importance of a criterion i relative to another criterion j is graded based on a scale of 1 to 9 as shown in table 5 (Saaty, 2008). The survey was designed to determine which criteria are considered by the respondent to be more important, and how much more, on a scale of 1 to 9 (table 5). Subsequently, they completed 6 pair-wise comparisons with respect to the social factor, 10 pair-wise comparisons for the environmental factor, and 3 pair-wise comparisons for the physical factor.

Table 4. Decision hierarchy level of AHP for the study

Hierarchy Level 1	**Hierarchy Level 2**	**Hierarchy Level 3**
Landfill Suitability	Social Factor	Distance from populated places
		Visibility from urban area and street centerlines
		Land use
		Distance from historic district, protected and recreation area
	Environmental Factor	Slope
		Elevation
		Soil condition
		Distance from surface water and groundwater sources
		Depth to groundwater
	Physical Factor	Road network
		Presence of public utilities
		Distance from waste transfer station

Table 5. Pair-wise comparison scale in AHP *(Saaty, 1990)*

Intensity of Importance	**Definition**
1	Equal Importance
3	Weak Importance of one over another
5	Essential or Strong Importance
7	Demonstrated Importance
9	Absolute Importance
2, 4, 6, 8	Intermediate values between the two adjacent judgements
Reciprocals of above nonzero	Of activity *i* has one of the above nonzero numbers assigned to it when compare with activity *j*, then *j* has the reciprocal value when compared with *i*

AHP Step 2: Producing a pair-wise comparison matrix

The pair-wise comparison results of the participated experts were arranged in a square matrix (*Mx*). The method is mathematically based on the solution of an Eigenvalue Eigenvector problem. A square matrix (*Mx*) for pairwise comparison of the landfill suitability analysis is expressed in Equation 1 (Saaty, 1990):

$$Mx = \begin{bmatrix} C_{11} & C_{12} & C_{13} & \cdots & C_{1n} \\ C_{21} & C_{33} & C_{23} & \cdots & C_{2n} \\ C_{31} & C_{32} & C_{33} & \cdots & C_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ C_{n1} & C_{n2} & C_{n3} & \cdots & C_{nn} \end{bmatrix} \quad (1)$$

$Mx = [C_{ij}]\ \forall\ i, j = 1, 2, 3, \ldots n$ for n criteria that influence the objective of the study, where, C_{ij} demonstrates the relative importance of the criteria C_i over C_j and the reciprocal will be C_{ii} or $1/C_{ji}\ \forall\ i \neq j$ and $C_{ii} = 1$ (Saaty, 1990). According to this equation, this study created 12 criteria in 3 categories (social, environmental, physical), so 4 by 4 matrix, 5 by 5 matrix, and 3 by 3 matrix were produced to conduct AHP methodology by means of a hierarchical analysis that establishes a priority scale within the criteria (Randazzo, et al., 2018). Subsequently, each matrix needs to be normalized, and eigenvector of each criterion are calculated by the mean of each row to get the factor weights. In other words, the factor weights need to be calculated by normalizing the individual eigenvectors associated with the principal eigenvector of the reciprocal ratio matrix (Saaty, 1990). Thus, an eigenvector is the factor weight of the study and it gives the relative importance of the criteria being compared. The first normalized Eigenvector of the matrix gives the ratio scale (weighting), and the Eigenvalue determines the consistency ratio. Detail numbers of each pair-wise square matrix of criteria are demonstrated in Chapter 5 (Analysis and results).

AHP Step 3: Calculating C.I (Consistency Index) and C.R (Consistency Ratio)

After producing the matrix, Consistency Index and Consistency Ratio need to be calculated. Consistency Index is deviation or degree of consistency using the equation 2. Thus, the Eigenvalue, which is regarded as Lamda (λ), needs to be calculated first in order to get the Consistency Index and the Consistency Ratio. We are able to get the eigenvalue by dividing the weighted total of the normalized matrix by the eigenvector. It is important to get consistency of answer because otherwise inconsistency of survey results regarding the expert judgement may occur. Interestingly, the AHP allows for inconsistency because in making judgement people are more likely to be inconsistent than cardinally consistent because they cannot estimate measurement values precisely (Saaty, 2003).

However, if the Consistency Ratio of the judgement is greater than 10%, the subject judgements to pair-wise comparison need to be revised. Whereas, if the value of the Consistency Ratio is smaller than or equal to 10%, the inconsistency of the judgement is acceptable. The mathematical form for the calculation of Consistency Index, CI, is represented by Equation 2:

$$CI = \frac{\lambda max - n}{n - 1} \tag{2}$$

Where λ_{max} is the average of all eigenvalue of the matrix, and *n* is the number of criteria of the matrix. Then, the Consistency Index can be compared to that of a random matrix, the Random Consistency Index (RI), and the CR, Consistency Ratio, is represented by Equation 3:

$$CR = \frac{CI}{RI} \tag{3}$$

The reason for the Consistency Ratio is that it is important to get consistency of answer because inconsistency of the survey results regarding the expert judgement may occur. Thus, the Consistency ratio is a comparison between the Consistency Index of the survey and Random Consistency Index, which are already provided by Satty who developed the AHP. The Random Index utilized for different matrix sizes are shown in table 5 as below.

Table 6. RI values for different matrix sizes *(Donegan & Dodd, 1991)*

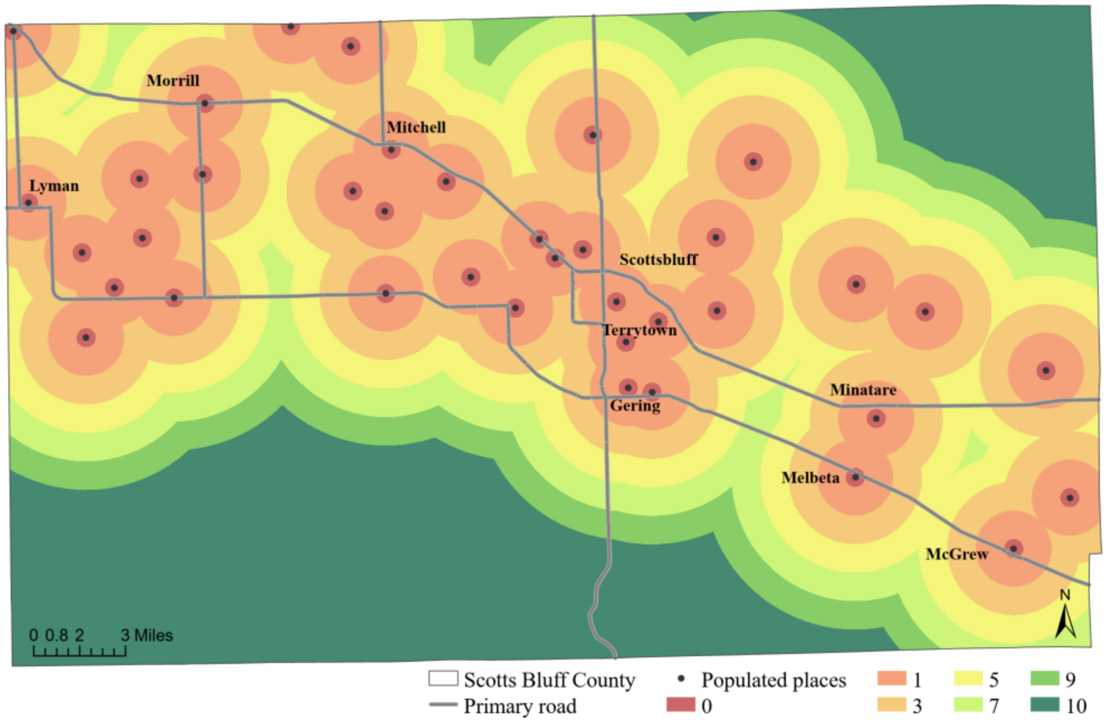
n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

After all the steps, finally, the priority vector of each criterion was used as a “weight”, and then assigned to each factor. The landfill suitability was assessed based on the simple system of weighted summation (SAW, Simple Additive Weighting) and the mathematical equation is described by the following Equation 4 (Yoon & Hwang, 1995):

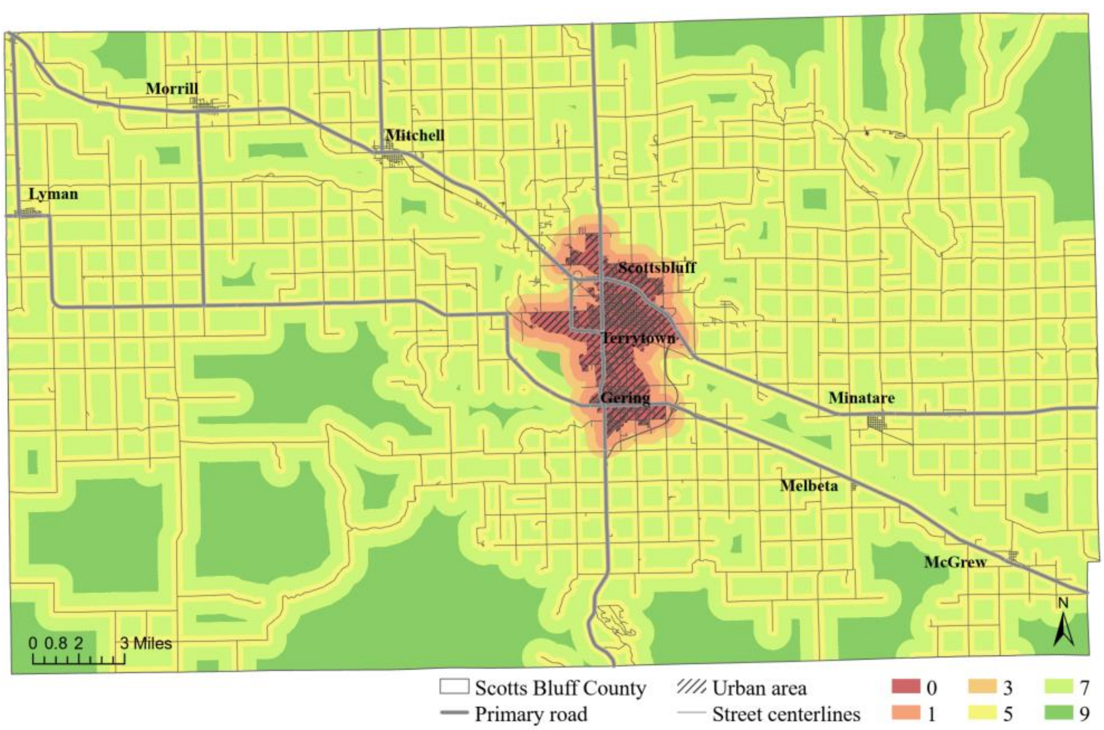
$$RI_j = \sum_{i=1}^{n} w_j v_{ij} \qquad \textbf{(4)}$$

Where RI_j is the suitability index for the area *j*, w_j is normalized importance of the weight given to the criterion *j*, v_{ij} is the priority value of the area *i* with respect to the criterion *j*, *n* is the total number of the criteria. The final suitability map was generated with a weighted overlay and raster calculator geoprocessing tools using GIS to complete the step, so twelve input map layers were produced, and the weights were applied according to each layer to be calculated. Figure 5 illustrates layer maps of 12 criteria with the road network and communities’ location. Each map was reclassified based on the grading structure using a scale of 0 to 10.

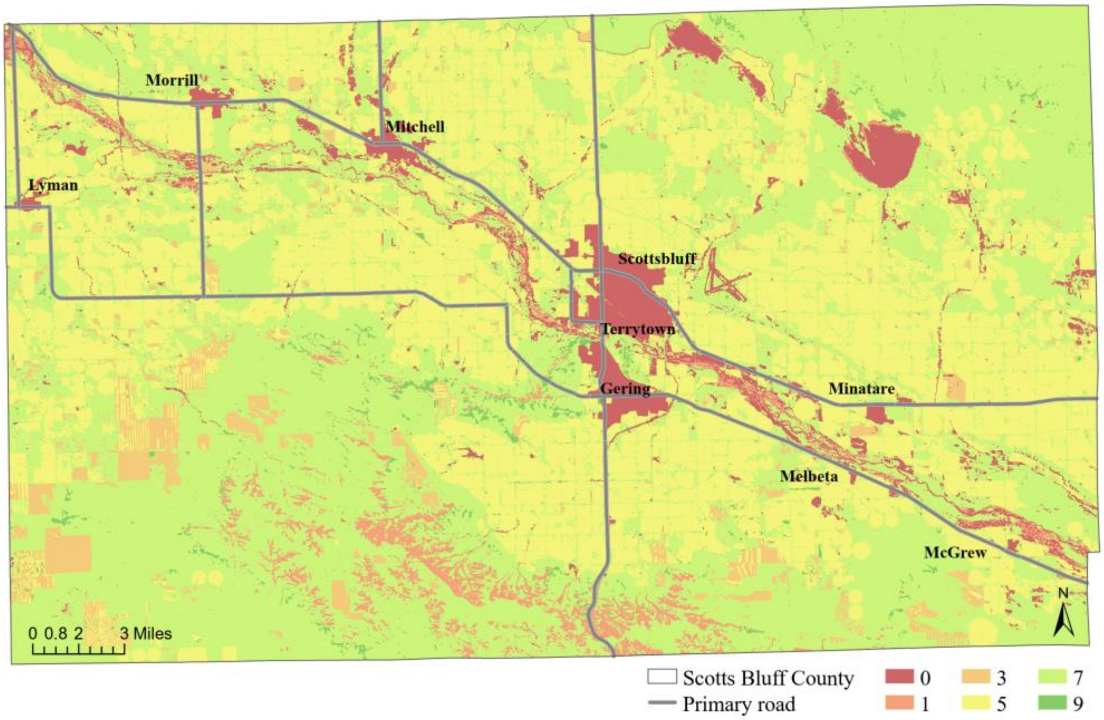
Figure 5. Layer map of each criterion



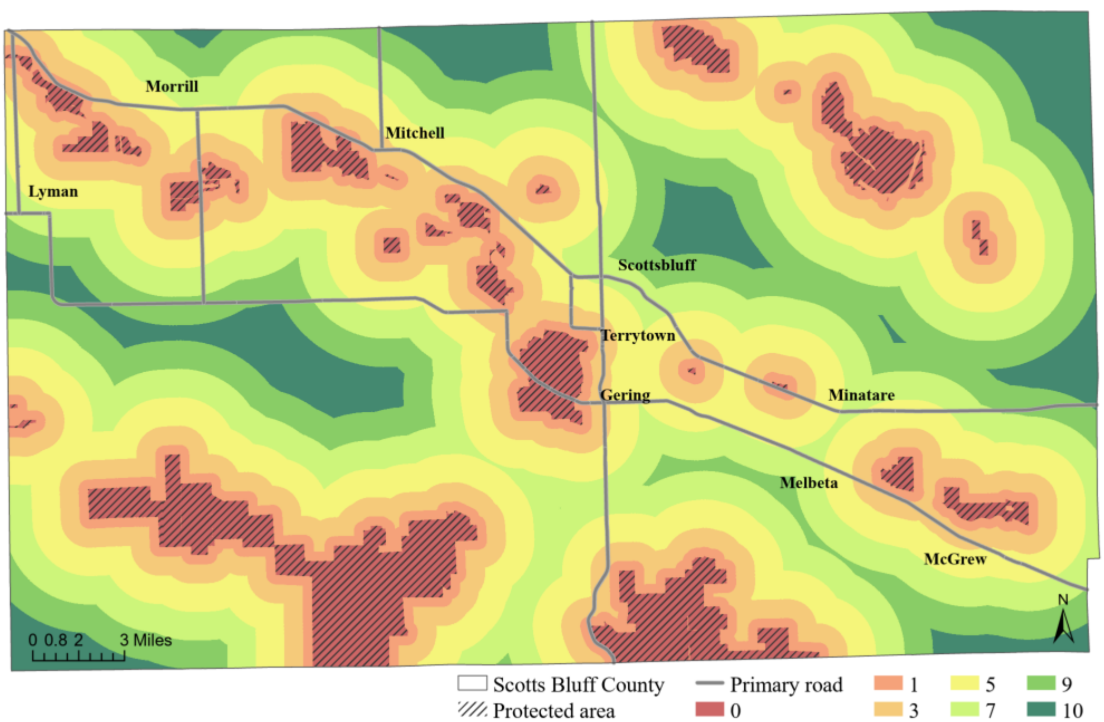
(a) Distance from populated places



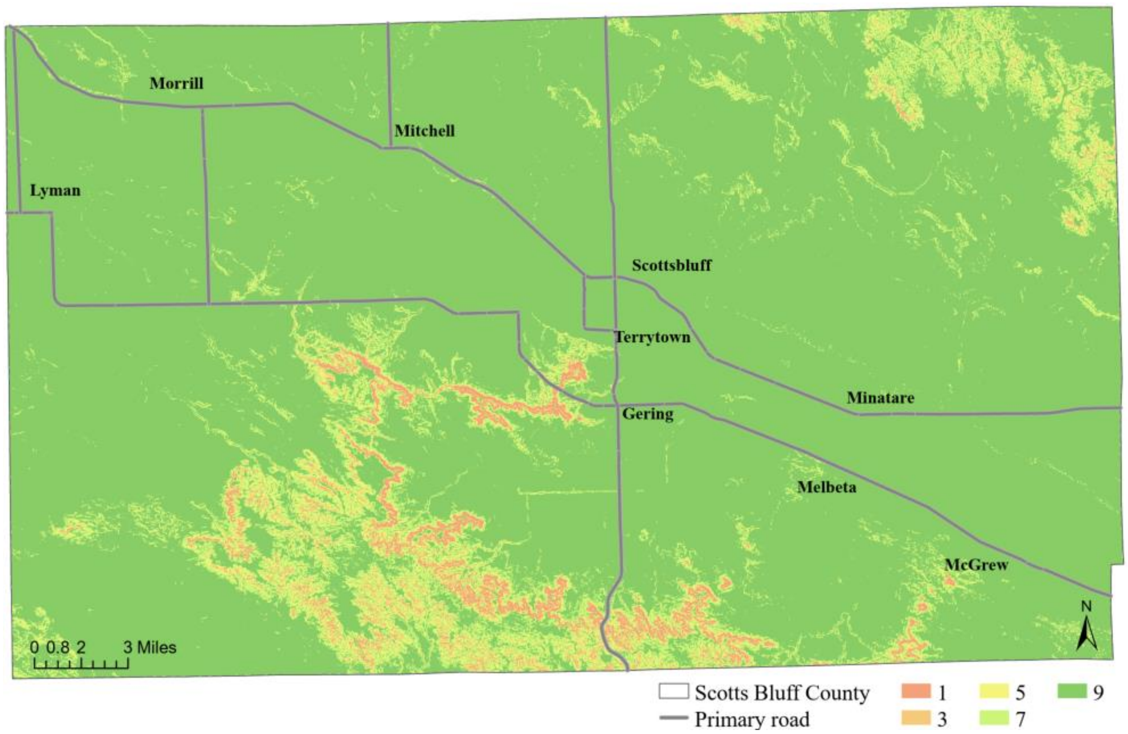
(b) Visibility from urban area and street centerlines



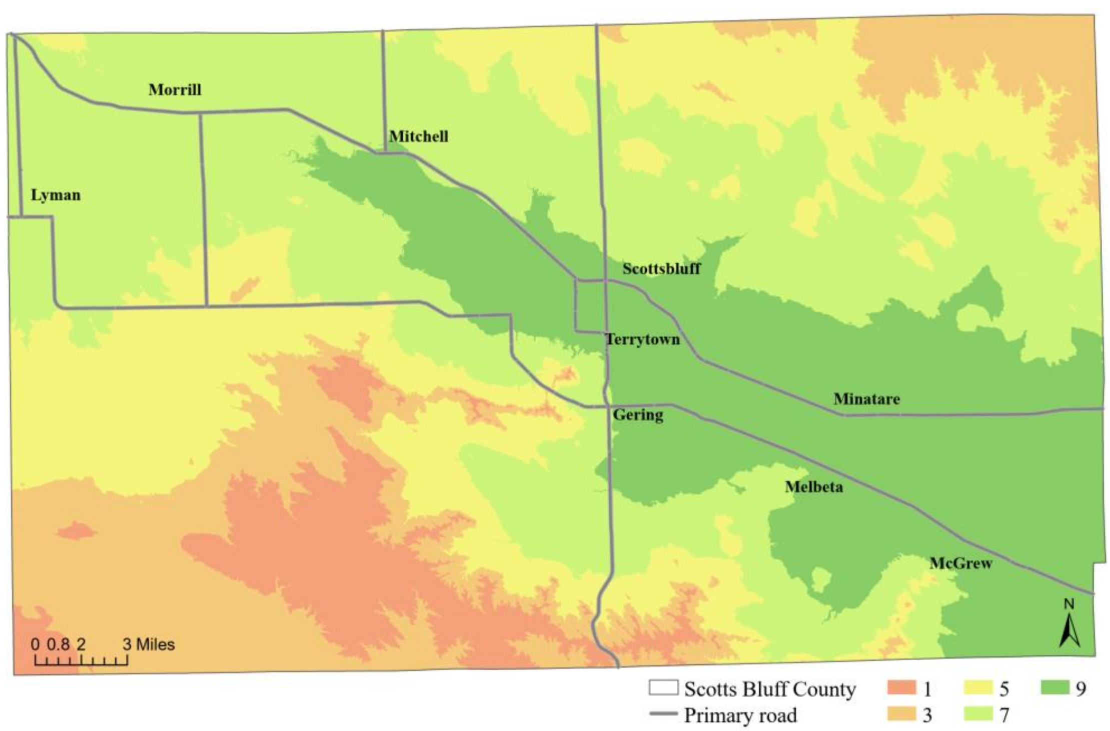
(c) Land use



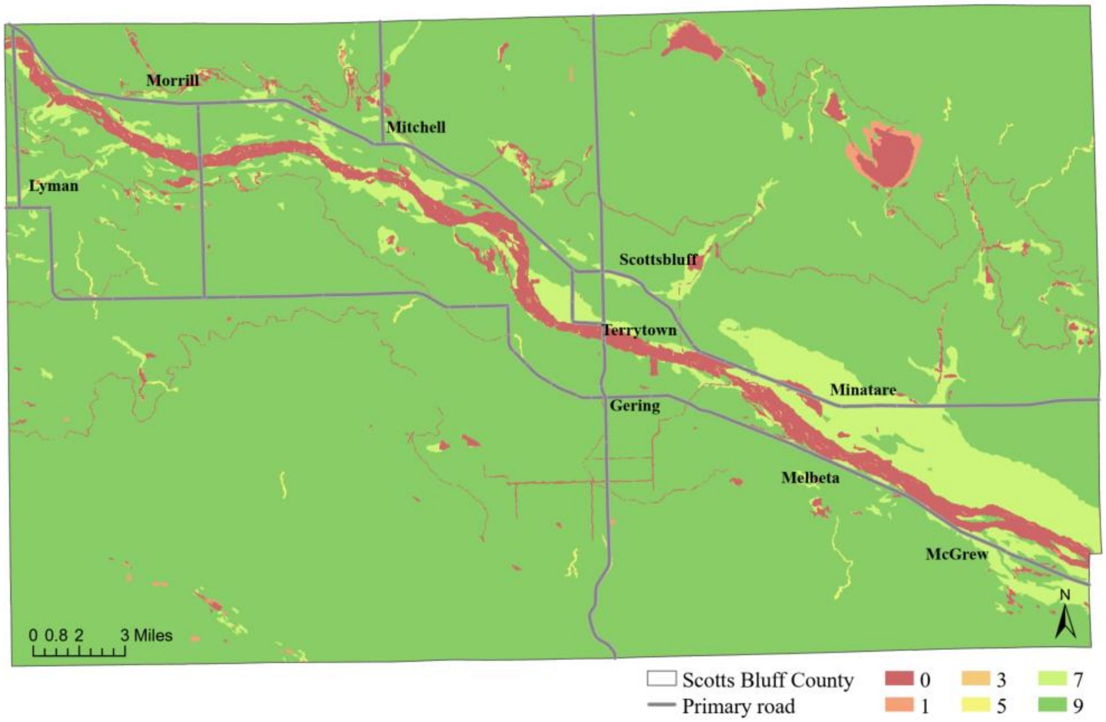
(d) Distance from historic district and protected areas



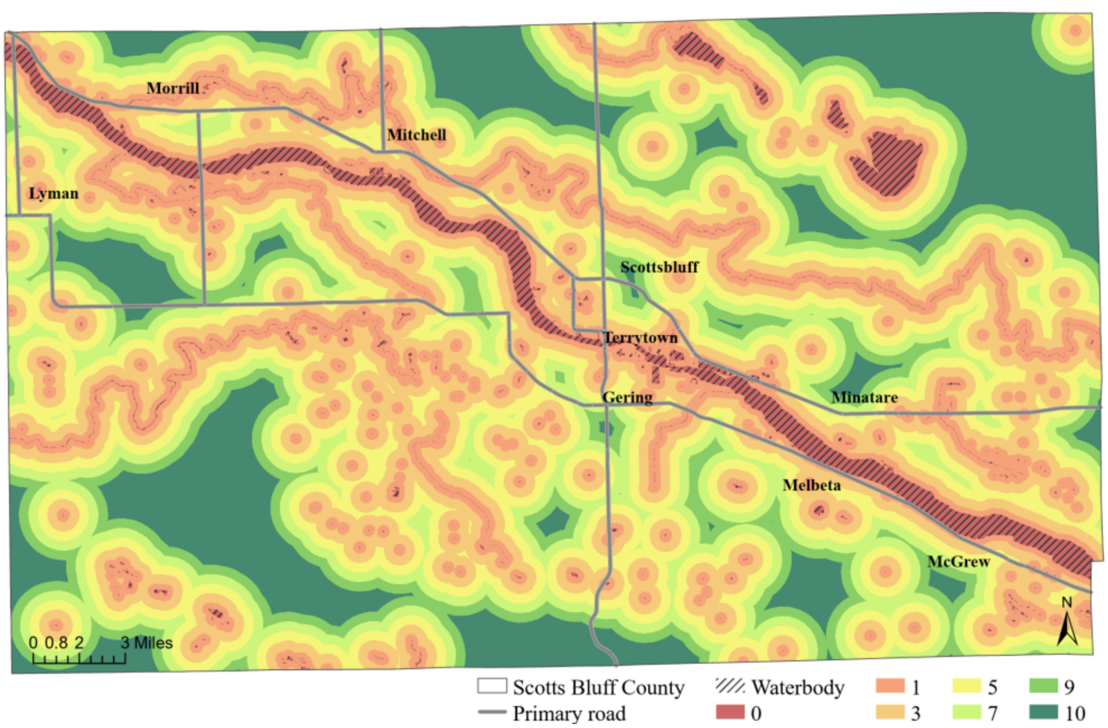
(e) Slope



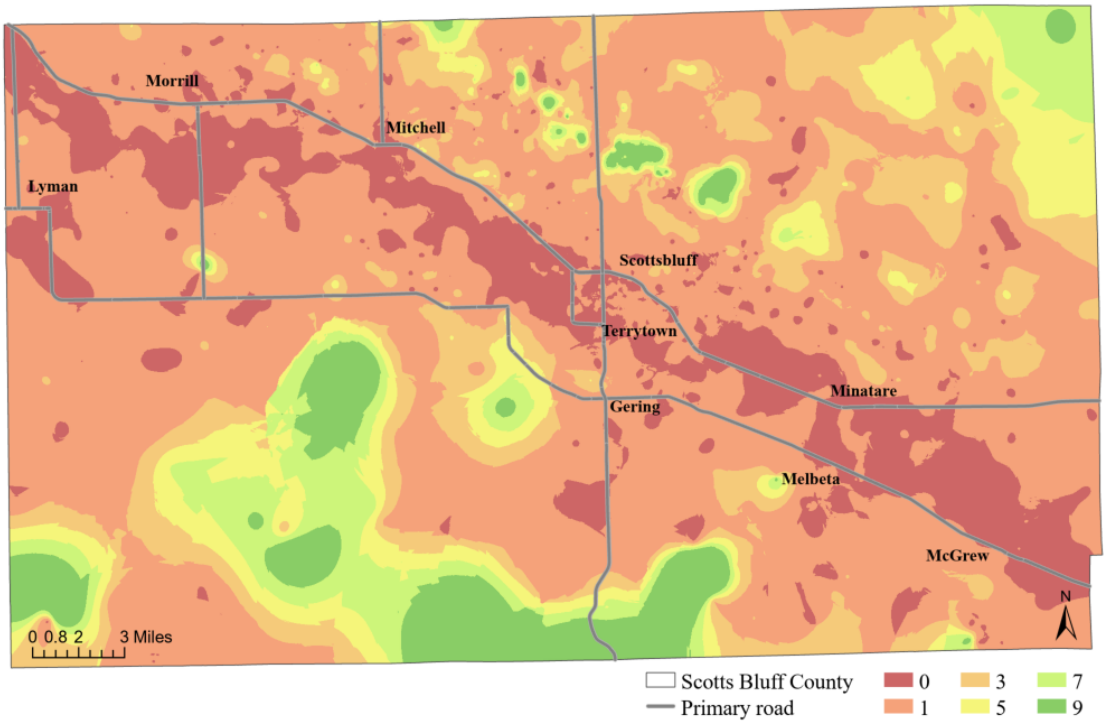
(f) Elevation



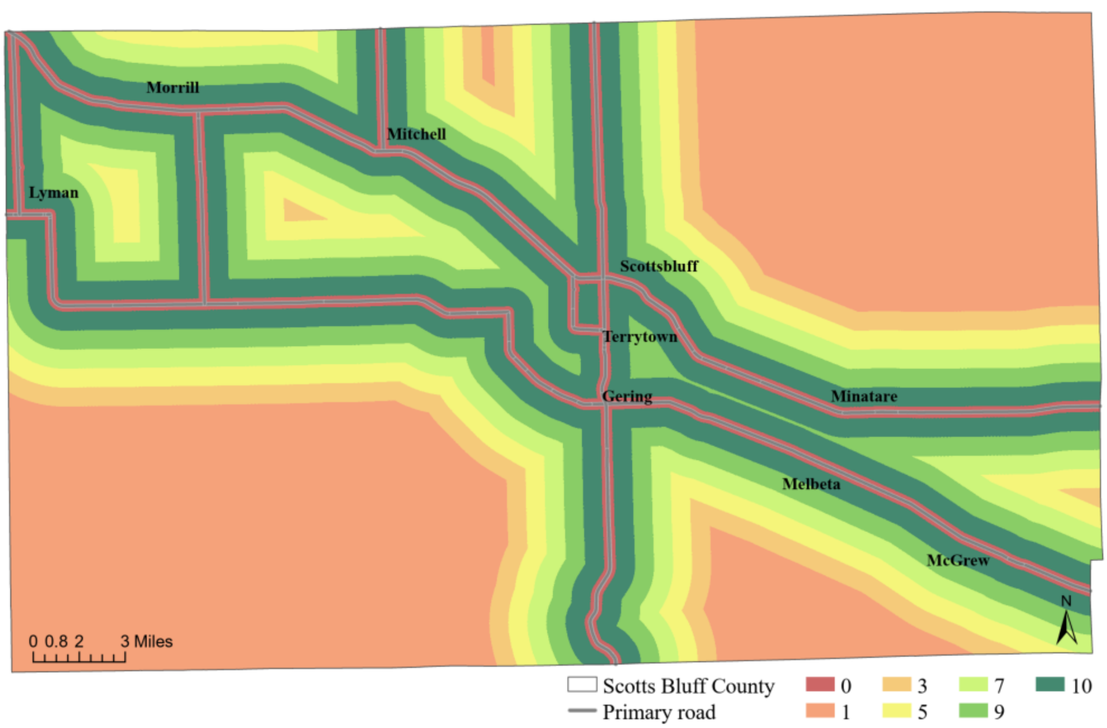
(g) Soil condition



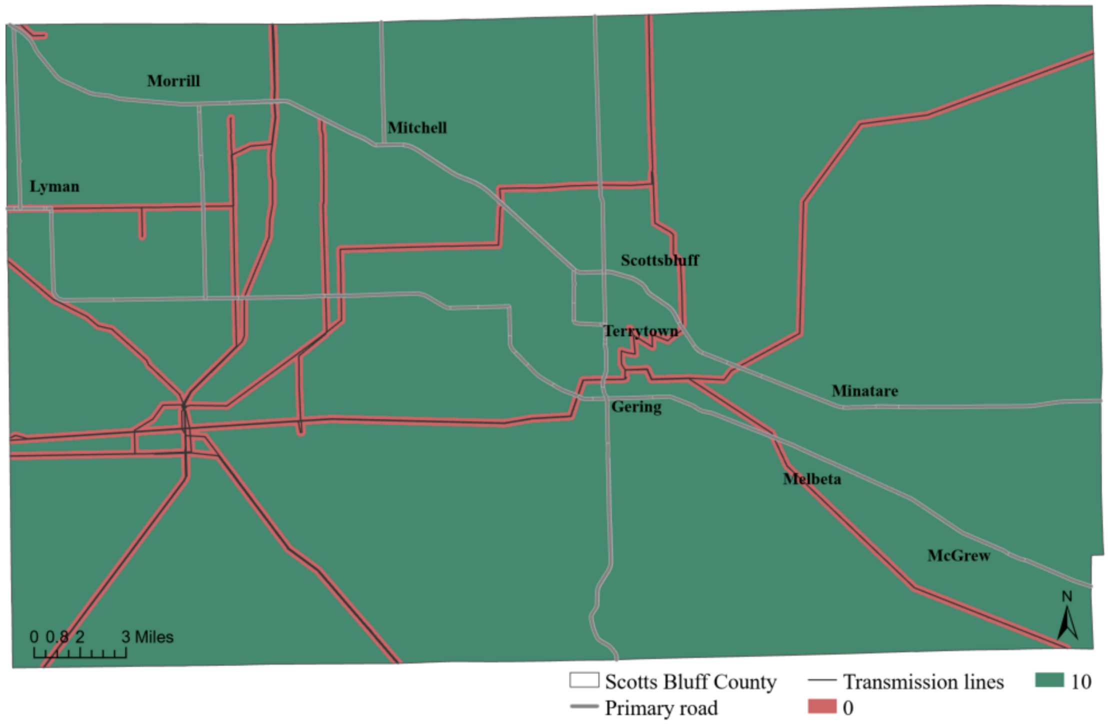
(h) Distance from surface water bodies



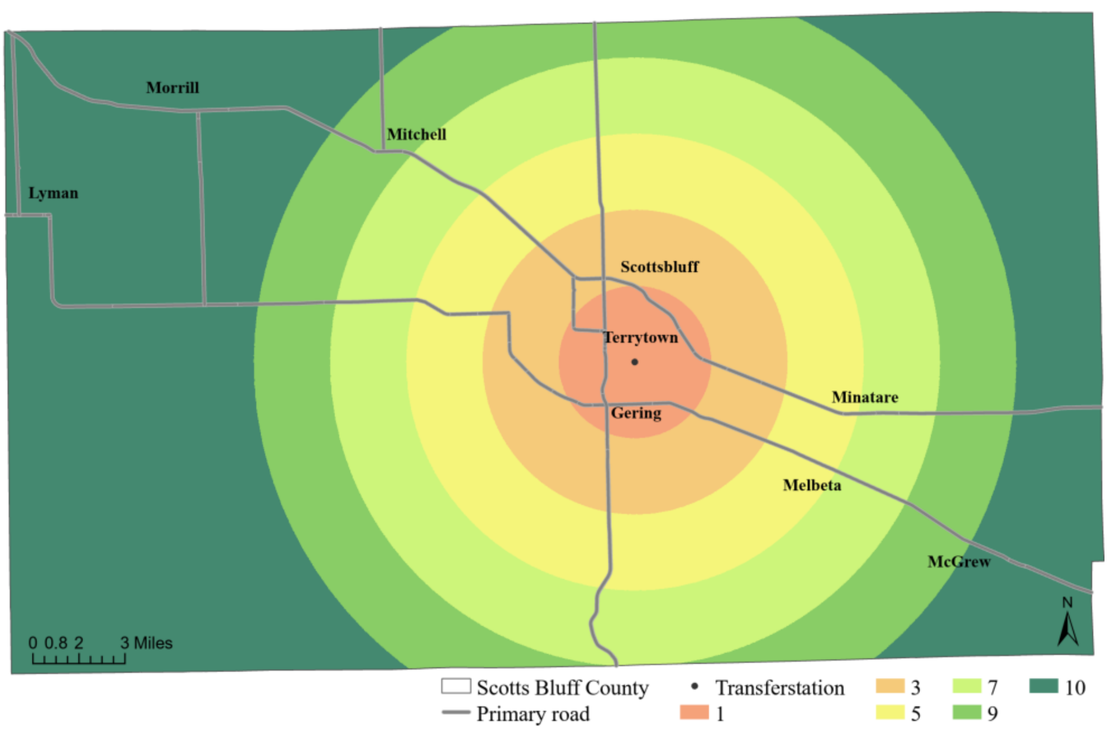
(i) Depth to groundwater



(j) Road network



(k) Presence of public utilities



(l) Distance from waste transfer station

3.3. Data Collection

The landfill siting analysis requires a substantial amount of information collection in order to progress each step for the study. Thus, various data was acquired from a variety of public and private sources. The collected data was organized, reclassified, converted and stored using GIS Pro software and an Excel spreadsheet. In this study, 12 input map layers were used including land use and land cover, settlement (urban area and populated places), visibility from street centerlines, historic district, and protected and recreational area, topography (slope and elevation), soil condition (soil flooding frequency, soil erodibility factor, soil hydric class), distance from surface water and groundwater source, depth to groundwater table, road network, presence of public utilities (water and electricity), and distance from waste transfer station. 6 input map layers were also applied for the first step of the process identifying the primary suitable areas including geology, soil type, vegetation type, topographic regions, airport location, and wetlands. The source and the format of data are described in table 6. NAD (North America Datum) 1983 State Plane Nebraska FIPS 2600 (meter) was used for the projected coordinate system for this study.

The information of the study area was collected through the previous literatures and interviews answered by the residents and other related sources (Wenzel, Cady, & Waite, 1946) (Western Nebraska Regional Landfill: A community Project, 2019). Field work was also progressed to get a sense of geographic characteristics of the study area and meet the residents in-person to get their thoughts and opinions. A few residents who are living close to the current landfill location of the study area agreed to have an interview and provided related information.

Table 7. GIS data collection

<table>
<tr><th>Dataset</th><th>Format</th><th>Source of data</th></tr>
<tr><td>County boundary</td><td>Vector polygon
– ESRI Shapefile</td><td>The home of the U.S. Government's open data (https://www.data.gov)</td></tr>
<tr><td>Parcels</td><td>Vector polygon
– ESRI Shapefile</td><td>Nebraska Office of the CIO (https://cio.nebraska.gov/servicedesk/index.html)</td></tr>
<tr><td>Elevation</td><td rowspan="2">DEM (3 meter)
– GeoTIFF</td><td rowspan="10">United States Department of Agriculture, Geospatial data gateway (https://datagateway.nrcs.usda.gov)</td></tr>
<tr><td>Slope</td></tr>
<tr><td>Conservation easements</td><td rowspan="2">Vector areas and points
– ESRI Shapefile</td></tr>
<tr><td>Urban area</td></tr>
<tr><td>Populated places</td><td>Vector points
– ESRI Shapefile</td></tr>
<tr><td>Geology</td><td>Vector polygon
– ESRI Shapefile</td></tr>
<tr><td>Hydrography</td><td>Vector point, line, and area
– ESRI Shapefile</td></tr>
<tr><td>Land cover</td><td>GeoTIFF</td></tr>
<tr><td>Roads</td><td>Vector lines
– ESRI Shapefile</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Soil flooding frequency</td><td rowspan="3">GeoTIFF</td><td rowspan="3">Esri, Living atlas of the world (https://livingatlas.arcgis.com/en/home/)</td></tr>
<tr><td>Soil erodibility factor</td></tr>
<tr><td>Soil hydric class</td></tr>
<tr><td>Electric transmission line</td><td>Vector lines
– ESRI Shapefile</td><td rowspan="2">ArcGIS Hub (https://hub.arcgis.com/datasets/nebraska::airports)</td></tr>
<tr><td>Airports</td><td>Vector point
– ESRI Shapefile</td></tr>
<tr><td>Topographic regions</td><td rowspan="2">Vector polygon
– ESRI Shapefile</td><td rowspan="3">University of Nebraska Lincoln, School of Natural Resources (http://snr.unl.edu/data/geographygis/)</td></tr>
<tr><td>Soil</td></tr>
<tr><td>Well</td><td>Vector points</td></tr>
</table>

Landfill operator and owners, experts in the planning and engineering fields, and consultants who are working in waste management section in Nebraska were randomly chosen and asked to participate in the survey as related experts who can provide their judgement regarding the evaluating criteria. Because planner, engineer, environmental official, and landfill owner would be the primary people in the decision-making process of landfill placement, this study categorized the participants in four different groups.

The introductory email including the explanation about the survey and the description about each criterion was sent to 180 potential participants as seen in appendices. Total thirty-two experts agreed to take place in the study and responded the introductory email and completed the survey. Some of them provided their opinion and thoughts about the landfill placement process and important criteria that influence surrounding environment and community. The survey was established by using a free web based AHP solution tool for decision making processes (https://bpmsg.com/ahp/) (Goepel, 2018). The participants received a link (https://bpmsg.com/ahp/ahp-hiergini.php?sc=zAhatu) connected to the website and completed the survey by using their private computer and the survey was conducted wherever the participant wanted.

The email addresses of potential participants were obtained through local and federal government official websites, and of the participants several were the alumni of the Master of Community and Regional Planning program at the University of Nebraska-Lincoln. It was notified to them in advance that their personal information and the specific results of the judgement will not be used or distributed for future research studies.

Chapter 4 Criteria

Criteria that have impacts on determining the landfill sites can be classified as factors and constraints. Developing a list of evaluating criteria for ranking potential landfill sites is the most important step for the study because potential landfill sites should meet the standards of criteria to be highly ranked. However, identifying a number of criteria and categorizing them in different hierarchical levels such as social, environmental, economic, and technical is not a simple process because the criteria are organically connected as a causal relationship. Moreover, some criteria can be included in several categories and some categories are ambiguous to cover the included criteria. For example, distance between the landfill and populated places has an impact on not only residents' health risk but also property value, so it can be categorized as a social factor or economic factor. It means that no single set of criteria is available for the process that can apply to all regions, but general criteria for siting landfills is summarized in table 8.

According to previous studies, environmental criteria related to water resources and topography were always included in the criteria to assess potential landfill sites (Kontos, Komilis, & Halvadakis, 2003) (Sener, Suzen, & Doyuran, 2006) (Kara & Doratli, 2012) (Randazzo, et al., 2018) (Kamdar, Ali, Bennui, Techato, & Jutidamrongphan, 2019). Environmental criteria are significant in deciding proper areas for a landfill because severe contamination due to landfill leachates or landfill gas emissions can present a major threat to the surroundings and it leads to permanent damage to environmental quality (Kamdar, Ali, Bennui, Techato, & Jutidamrongphan, 2019). Thus, 5 criteria as environmental factors were considered, and 4 criteria as social factors and 3 criteria as physical factors were decided to evaluate potential sites.

Table 8. Considered criteria in the previous studies

Title	Author	Criteria for suitability study
Siting MSW landfills on Lesvos island with a GIS-based methodology	(Kontos, Komilis, & Halvadakis, 2003)	• Social/Anthropocentric criteria Distance from urban area, Visibility from residential areas, Land use, Land property • Environmental/Geological criteria Hydrogeology, Distance of water sources, Type of natural vegetation, Downstream characteristics, Ecology, Size of upstream hydrologic basin, Current environmental degradation • Technical/Economical criteria Cover soil, Landfill depth, Design life, site orientation, Site access, Presence of public utilities, Distance from waste production centers
Landfill site selection by using geographic information systems	(Sener, Suzen, & Doyuran, 2006)	• Natural/Environmental factors Surface water, Flood, Swamp, Aquifer, Lithology Structural constraints, Slope, Elevation • Artificial factors Roads, Pipeline and electricity, Urban centers, Land use, Airport, Villages
Compliance factors within a GIS-based framework for landfill siting	(Sadak, El-Fadel, & Freiha, 2006)	• Environmental criteria Surface water, Ground water, Natural reserves, Rainfall, Public water supplies • Socio-cultural/economic criteria Land use, Population, Cultural environment, Land cost • Engineering/infrastructure criteria Geology, Fault areas, Soil, Topography, Roads, Sewer, Electric lines, stations
Landfill site selection using spatial information technologies and AHP: Beijing, China	(Guiqin, Li, Guoxue, & Lijun, 2009)	• Environmental criteria Men and animal habitats, Surface water, Ground water, Distance from airfields, Agricultural land, Forest land, Special land, Land shape • Economic criteria Price of land, Distance of transport

Application of GIS/AHP in siting sanitary landfill: a case study in Northern Cyprus	(Kara & Doratli, 2012)	• Economic criteria Distance to waste generation centers, Distance for roads, Slope • Natural criteria Distance from surface waters, Distance from groundwaters, Distance from ESA, Distance from vegetation, Soil productivity, Soil permeability • Physical criteria Distance from settlements, Distance from cultural sites, Distance from quarry areas • Environmental criteria Rock permeability, Distance from settlements, Average annual rainfall, Peak ground acceleration, Distance from surface waters • Economic criteria Land slope, Distance from roads, Land use
Landfill site selection for municipal solid waste by using AHP method in GIS environment: Sicily, Italy	(Randazzo, et al., 2018)	• Environmental criteria Rock permeability, Distance from settlements, Average annual rainfall, Peak ground acceleration, Distance from surface waters • Economic criteria Land slope, Distance from roads, Land use
Municipal solid waste landfill siting using an integrated GIS-AHP approach: A case study from Songkhla, Thailand	(Kamdar, Ali, Bennui, Techato, & Jutidamrongphan, 2019)	• Morphological criteria Slope, Elevation, Soil texture • Environmental criteria Aquifer, Groundwater table, Surface water, Geological fault areas, Floodplain • Socio-economic criteria Road network, Waste production centers, Residential areas, Historical places, Land use

4.1. Social factor

Distance from populated places

Siting municipal solid waste landfills close to populated places cause not only many environmental problems but also public complaints. Because it entails a variety of issues such as the health risk of residents, property values, and residents' quality of life, proper distance of potential landfill sites from residential areas should be significantly considered. This factor is mainly included in most of the previous studies analyzing landfill suitability in a community (Baban & Flannagan, 1998) (Kontos, Komilis, & Halvadakis, 2003) (Sener, Suzen, & Doyuran, 2006) (Kara & Doratli, 2012) (Randazzo, et al., 2018) (Kamdar, Ali, Bennui, Techato, & Jutidamrongphan, 2019). The importance of the surroundings of the landfill is outlined in Title 132 – Integrated Solid Waste Management Regulations, Chapter 3 (002.02E) that the landfill application should include a description of the population density of the proposed facility and of the area surrounding the facility within one mile of the facility boundaries (Nebraska Department of Environmental Quality, 2016).

Moreover, it is predictable that odor is the issue most concerned in relation to a landfill, and many previous studies focusing on measuring landfill odors and its impacts exist. One of the engineers who participated in the survey mentioned that landfill odors usually spread up to 2 miles from the landfill. Thus, it is possible to assume that distance between a landfill and the residential areas or populated places is significantly important to reduce the potential impacts caused by landfill odors. Therefore, a 0.5 km buffer zone was applied to limit the area which are unacceptable for siting landfill and the grade of 0 was assigned for the limitation. Additional distance was gradually set with an interval of 1.5 km, and 1, 3, 5, 7, 9, and 10 grading points were given to each distance respectively.

Land use

Land use shows how people use the landscape whether for development, conservation, or mixed uses. Current land use affects landfill placement with urban sprawl, farmland preservation, and population growth. Thus, planned future development and improper areas should be excluded in the siting process. The standard of assigning grades to land use depends on studies' purpose and researchers' objectives, so there is a variety of standards in categorizing the criterion of land use. For instance, Kontos (2003) distinguished agricultural and pasture lands in detail while Alavi (2013) classified land use as residential, agricultural, industrial, and unused land (Kamdar, Ali, Bennui, Techato, & Jutidamrongphan, 2019). The purpose of this criterion is protecting areas where damage is irreparable when it affects productive areas compared to other lands. Hence, urban land, open water, and roads were assigned the grade of 0 as a limited area to build a landfill. Subsequently, riparian/deciduous/ponderosa forest, woodlands, and wetlands were given the value 1 because they are regarded as protected lands in Nebraska. The grade of 10 were not used for this criterion because there would be no perfectly suitable land for siting a landfill.

Visibility from urban area and street centerlines

Visual contact from urban area and street centerlines would be considered because it can increase community complaints because of unpleasant view and other potential negative impacts in relation to the landfill. When an existing landfill considers a landfill expansion, they often conduct a visual assessment of the development whether the proposed landfill expansion will significantly impact the surrounding properties and community. Thus, the areas of urban area and street centerlines were primarily restricted with the value 0 (worst sites). Because less than 1 km from the urban area may affect visibility based on the current landfill location visibility, a 0.5 km buffer zone was created to assign the grade of 1 and the value 3 was given to the range between 0.5 km and 1 km.

There is a regulation that a solid waste disposal area should not be located within 1,000 feet (approximately 0.3 km) from the nearest edge of an existing right-of-way of any state, interstate or federal highway (Nebraska Department of Environmental Quality, 2016). On the basis of the regulation, a 0.3 km buffer zone was created, and the grade of 5 were assigned to the buffer zone because a buffer zone of grade 5 included the 0.5 km buffer zone of urban area.

Historic district and protected area

Historical/archeological sites and protected areas such as national monuments and recreation areas should be avoided in locating a landfill. Because developing a landfill in one of these areas can damage the environment and impede a successfully operated landfill, siting a landfill within the areas must be forbidden. The national monument in the study area is a famous landmark in Nebraska, but, interestingly, the current landfill site is located within a close distance from this area.

According to several studies, many countries have tried to protect those areas as unsuitable for landfill sites by providing a specific distance (Baban & Flannagan, 1998) (Kontos, Komilis, & Halvadakis, 2003) (Sadak, El-Fadel, & Freiha, 2006) (Bunruankaew & Murayama, 2011) (Kara & Doratli, 2012) (Ali & Ahmand, 2020). Thus, the protected areas including historic districts, recreational areas, and other privately protected areas were regarded as an excluded zone by assigning the grade of 0. A 0.5 km buffer zone was created to protect the area and it was given to the value 1. Subsequently, 3, 5, 7, 9, and 10 grading point were assigned for every 1 km distance.

4.2. Environmental factor

Slope

Slope and elevation of land surface are essential factors to consider in the landfill siting process because steep slopes will lead to higher excavation costs for construction and retention (Kamdar, Ali, Bennui, Techato, & Jutidamrongphan, 2019).

The study area is an overall flat area, and its maximum slope is 58 degree. According to the studies, land slopes between 0 degree and 10 degree have been suggested as being proper for constructing a landfill (Sener, Suzen, & Doyuran, 2006) (Effat & Hegazy, 2012). Kamdar (2019) defined the standard for slope writing that areas with a slope greater than 15 degree were considered to be unsuitable while less than 5 degree were considered as highly suitable. Based on the studies, land slopes greater than 20 degree were given to the grade of 1, which is the lowest value, and less than 5 degree were assigned to the value of 9. The intermediate grades were assigned with an interval of 5 degree. The value 0 was not used because there is no specific regulation regarding land slopes and elevation in siting a landfill.

Elevation

High elevation is also inappropriate for landfill sites because it would cause difficulties during construction while too low of an elevation would have an impact on runoff drainage. The slope of the land surface will be calculated on the pixel basis using the digital elevation model (DEM) of the study area.

The elevation of the study area is generally moderate. Thus, natural break classification method in ArcGIS Pro was used to classify the standard. The natural break classification method is based on natural groupings inherent in the data and classes are created in a way that best groups similar values together and maximizes the differences between classes (Esri, ArcGIS Pro, n.d.).

Soil Condition

Soil condition can provide useful information in the landfill location siting process. For example, permeable soils will provide less protection and may require installing additional controls within the landfill. It can have a substantial impact on groundwater, surface water bodies, and vegetation because of the possibility of pollutants. Thus, soil hydric class, soil erodibility factor, and soil flooding frequency would be contemplated together to measure the general soil condition. In the case of this study, soil hydric class, soil erodibility factor, and soil flooding frequency were equally calculated to create a map layer of soil condition.

Hydric soils are soils that form under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part of the soil (United States Department of Agriculture, n.d.). Soil Erodibility Factor represents both susceptibility of soil to erosion and the rate of runoff. Erodibility factor is a value between 0 and 1. If values of K for soils is greater than 0.4, it tends to crust and produce high rates of runoff (Michigan State University, 2002). Lastly, soil flooding frequency provides an estimate of the likelihood of flooding in a given year (Esri, ArcGIS Online, 2017). It consists of seven classes from None (no reasonable possibility of flooding) to Very frequent (Flooding is likely to occur very often). Based on the information, soils that tend to very frequently flooding and are hydric are scored as the grade of 0. The rest of classes are divided respectively as described in table 2 in the previous chapter, and soils that have a K value between 0 and 0.10 and are not hydric with very lower possibility to flooding were assigned to the grade of 10.

Distance to surface water bodies

According to Title 132 – Integrated Solid Waste Management Regulations, Chapter 3 (002.01), a landfill site should not be located in an area where the solid waste activities will have a detrimental effect on the waters of the state (Nebraska Department of Environmental Quality, 2016). Because a landfill site which is adjacent to any water sources can cause potential pollution, a certain distance of buffer zone should be maintained around significant water bodies such as ponds, lakes, rivers, and streams. Thus, the areas of surface water bodies were constrained in siting the landfill and assigned the grade of 0. Subsequently, a minimum buffer zone of 0.3 km was maintained to protect significant water bodies from direct contamination. Five buffer zones were created with a distance of 0.5 km, and the grade of 10 were given to the areas located 2.3 km away from the landfill.

Depth to groundwater table

It is described in Title 132 – Integrated Solid Waste Management Regulations, Chapter 5 (002.01) that the vertical separation between the lowest point of the lowest cell and the predicted maximum water table elevation shall be sufficient to maintain a ten (10) foot vertical distance between deposited waste and the water table elevation based on reliable existing regional data (Nebraska Department of Environmental Quality, 2016). Because improper leachate collection and liner system may influence the groundwater table, and a short vertical distance between the landfill and groundwater table leads to severe groundwater contamination that can have a huge impact on both people's health and environment. The vulnerability of groundwater to contaminants due to landfill has been frequently studied, and the methodologies of measuring groundwater table are various.

There are two interpolation methods in analyzing groundwater flow and physiochemical parameter distribution. Chen Jie (2013) stated that using Kriging method is more practical than IDW (Inverse Distance Weighting) method when estimating the spatial distribution of groundwater depth. Kriging is a geostatistical interpolation method that has proven useful in many fields because it has the capacity of producing a predict surface and provides some measures of the certainty of the prediction (Jie, Hanting, Hui, Jianhua, & Xuedi, 2013). Thus, depth to groundwater table layer was created based on static water level data, which was available by using well data, to decide the depth of groundwater in the study area. The static water level is the distance from the land surface (or the measuring point) to the water in the well (Buckley, Konda, LaFave, & Madison, 1998).

4.3. Physical factor

Road network

The criterion of distance from road network should be taken into account for the process of siting a landfill due to the greater or lesser accessibility to the location (Randazzo, et al., 2018). If the potential sites are located too far from the existing road network, it is inevitable to face excessive costs for the construction of connecting roads. However, according to Title 132 – Integrated Solid Waste Management Regulations, Chapter 3 (002.03), a solid waste disposal area should not be located within 1,000 feet from the nearest edge of an existing right-of-way of any state, interstate or federal highway. The reason for the regulation is that transportation of waste should not interrupt the stream of normal vehicular traffic. Therefore, a comprehensive criterion in relation to road network is needed. Thus, a 0.3 km buffer zone was created as an exclusionary zone with the value 0. Then, 1, 3, 5, 7, 9, and 10 grading points were sequentially assigned for every 1 km distance.

Distance from waste transfer station

Distance from potential landfill sites to the solid waste transfer station influences transportation costs. It is significantly related to the economic feasibility of a candidate landfill site. Although cost-effectiveness will vary, waste transfer stations generally become economically viable when the hauling distance to the disposal facility such as landfill is greater than 15 to 20 miles (United States Environmental Protection Agency, 2002). Hence, the distance of greater than 20 km was considered as highly suitable area and received the grade of 10. Based on the previous studies, 9, 7, 5, 3, and 1 grading points were assigned for the area sequentially subtracted 4km from 20km (Kontos, Komilis, & Halvadakis, 2003).

Presence of public utilities

The presence of public utilities such as electricity and water in proper proximity of the potential landfill sites is an important factor to consider. The absence of such utilities would generate additional costs to develop and operate solid waste disposal. However, a safety distance of 700 feet may be needed to reduce the exposure levels of high voltage transmission lines (Neuert, 1992). Thus, a 700 feet buffer zone was created as a constraint area and assigned the grade of 0. The public utilities were fairly distributed for the study area, so the distance of greater than 700 feet from the transmission lines was taken as the suitable area, which were assigned to the grade of 10.

Chapter 5 Analysis and Results

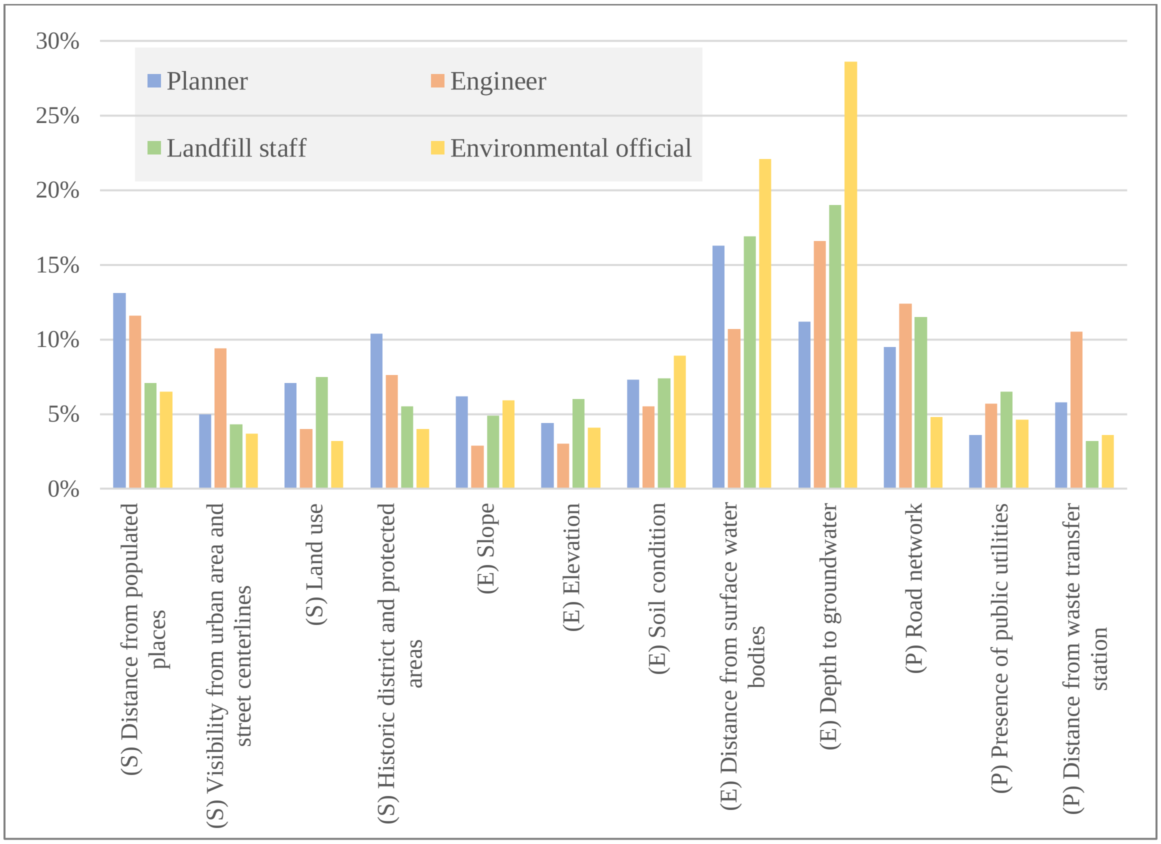
5.1. Analysis of factor weights by participants' group

It is worthwhile to note some findings about analysis of the factor weight before analyzing the final results. As it was mentioned earlier, the factor weight using AHP methodology was calculated based on 32 participants' judgement who work in the related fields: planning, engineering, current landfill, and environmental officials. Hence, it was assumed that participants will make different judgements on the pair-wise comparison of the criteria, accordingly, the derived factor weight will vary by their occupation and location. Even though they have common background information regarding MSW management and the landfill siting process, their interest and value toward the social, environmental, and physical factors that influence the decision can be totally different having been formed based on diverse experience.

The participants were divided into 4 groups: planner, engineer, landfill staff, and environmental official. As assumed before getting the results, the outcome was diverse. Figure 6 shows the different factor weights by the participants' group and the top 5 ranking criteria with different proportion based on each group are summarized in table 9.

In the case of the group of planners, they have highly considered the social factor compared to other groups as expected. As displayed in table 9, only the planners' group has two social factors, which are the 'Distance from populated places' and the 'Historic district and protected areas,' within the top 5 ranking of criteria while other groups have one social factor on their list. The 'Historic district and protected areas' (10.4%) criterion under the social factors were only on the list of the planners' group and its weight is the highest among the groups. Because planners focus on helping communities to improve

Figure 6. Factor weight of criteria by participants' group



*(S) = Social factor, (E) = Environmental factor, (P) = Physical factor

Table 9. Top 5 ranking of criteria by participants' group

	Planner	Engineer	Landfill staff	Environmental official
1	(E) Distance from surface water bodies	(E) Depth to groundwater	(E) Depth to groundwater	(E) Depth to groundwater
2	(S) Distance from populated places	(P) Road network	(E) Distance from surface water bodies	(E) Distance from surface water bodies
3	(E) Depth to groundwater	(S) Distance from populated places	(P) Road network	(E) Soil condition
4	(S) Historic district and protected areas	(E) Distance from surface water	(E) Soil condition	(S) Distance from populated places
5	(P) Road network	(P) Distance from waste transfer station	(S) Distance from populated places	(E) Slope

*(S) = Social factor, (E) = Environmental factor, (P) = Physical factor

and revitalize local areas, it can be assumed that they are likely to care more about the social factors which are related to communities' situation and surrounding circumstance. Thus, the criterion of 'Distance from populated places' (13.1%) placed in second as the highest among the groups.

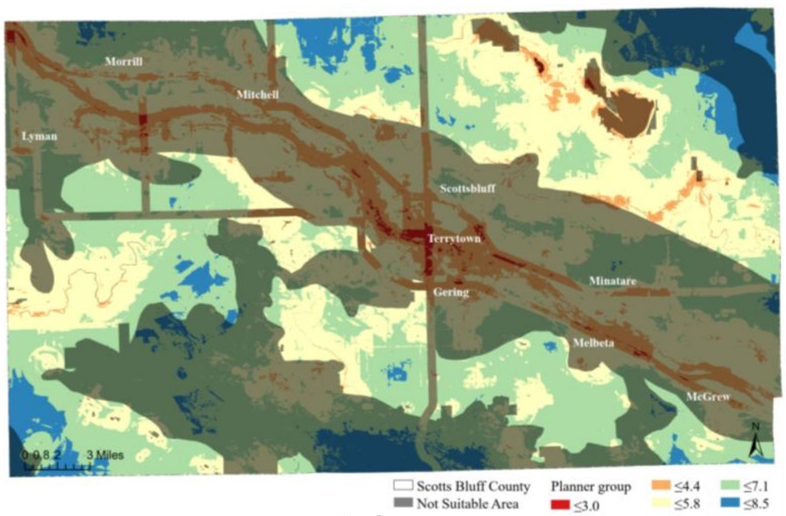
According to the survey results of the participants who are working as an engineer, they have tended to highly rank the criterion of 'Road network' and the criterion placed second on the list unlike others. Additionally, the physical factors including 'Road network' (12.4%) and 'Distance from waste transfer station' (10.5%) were significantly counted as an important component among the engineers' group compared to other groups which have only one physical factor within the top 5 ranking criteria as seen in figure 6 and table 9. In particular, the 'Distance from waste transfer station' criterion placed only on the list of the engineers' group and the criterion ranked as the highest among the groups. The reason for this can be assumed that engineers are likely to be more familiar with certain systems such as energy recovery and landfill gas treatment. Thus, they can think about the importance of the waste transfer station and its economic feasibility in the perspective of an engineer.

The group of landfill staff could understand more about the various issues regarding landfills than any other groups because of their practical experience. Thus, all of the factors that have been generally considered the most problematic are included on the list of the landfill staff's group such as the concerns related to water contamination and public opposition. Moreover, the proportion of their factor weights was fairly distributed through 12 criteria compared to other groups as shown in figure 6. The criteria of 'Depth to groundwater' and the 'Distance from surface water bodies' under the environmental factors were assigned with the factor weight of 19% and 16.9% respectively, which were regarded as the higher priority for landfill staff. It was thought that accessibility to existing road network would be the most significant factor because they are working on actual landfill sites. However, it was identified that the criterion of ‘Road network’ (4.8%) ranked third on the list. It means that they have recognized the environmental impacts due to landfills, accordingly, they generally pay attention to it and try to take care of its risk.

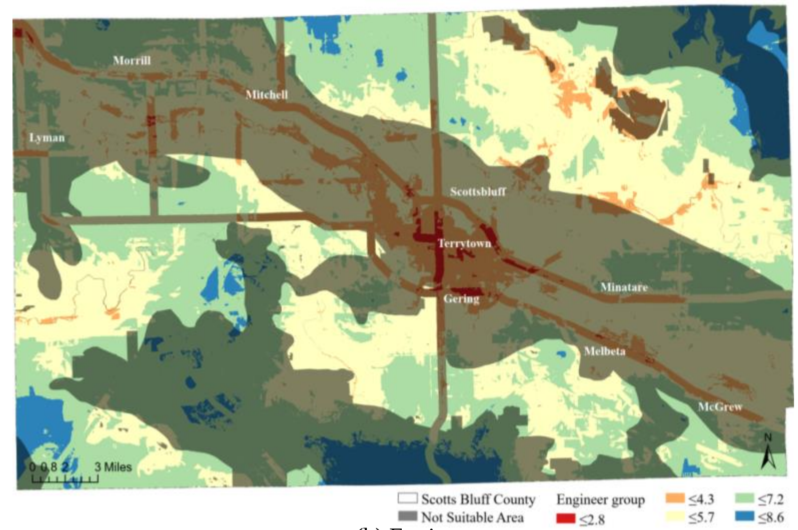
The results of the environmental officials’ group were extremely focused on the environmental factors as predicted. The factors associated with water were regarded as higher priority like other groups, but the ‘Slope’ criterion under the environmental factors placed on the list unlike others. The criteria of ‘Depth to groundwater’, ‘Distance from surface water bodies’ and ‘Soil condition’ were given the factor weight of 28.6%, 22.1%, and 8.9% respectively as the highest among the groups. Thus, it is clear that the environmental factors are the main concern to officials who are working in the department related to environmental quality, and it has to influence the decision-making process of landfill siting.

In conclusion, the criteria of ‘Distance from surface water bodies’ and ‘Depth to groundwater’ under the environmental factors and ‘Distance from populated places’ under the social factors commonly ranked on the top 5 list for every group. It can be interpreted that environmental contamination, especially water pollution, and public opposition are considered important issues for the related experts regardless of their occupation. Hence, the criteria should be preliminary discussed when related stakeholders comprise their opinions regarding landfill siting.

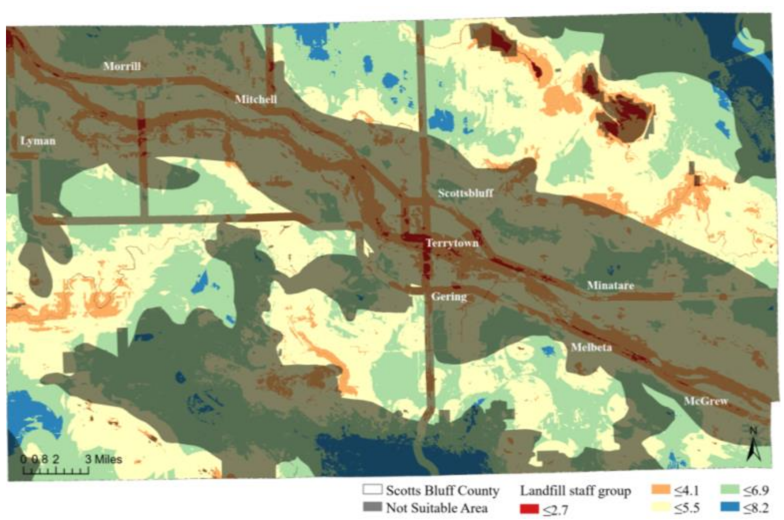
Figure 7. Suitability map by participants' group



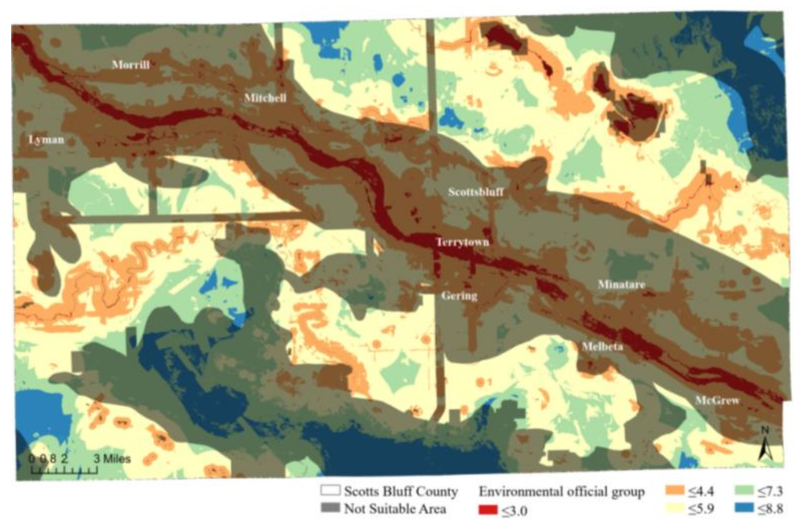
(a) Planner



(b) Engineer



(c) Landfill staff



(d) Environmental official

The suitability map by participants' group is shown in figure 7 and the most suitable areas and the least suitable areas, which are illustrated as blue color and red color, are slightly different according to each group.

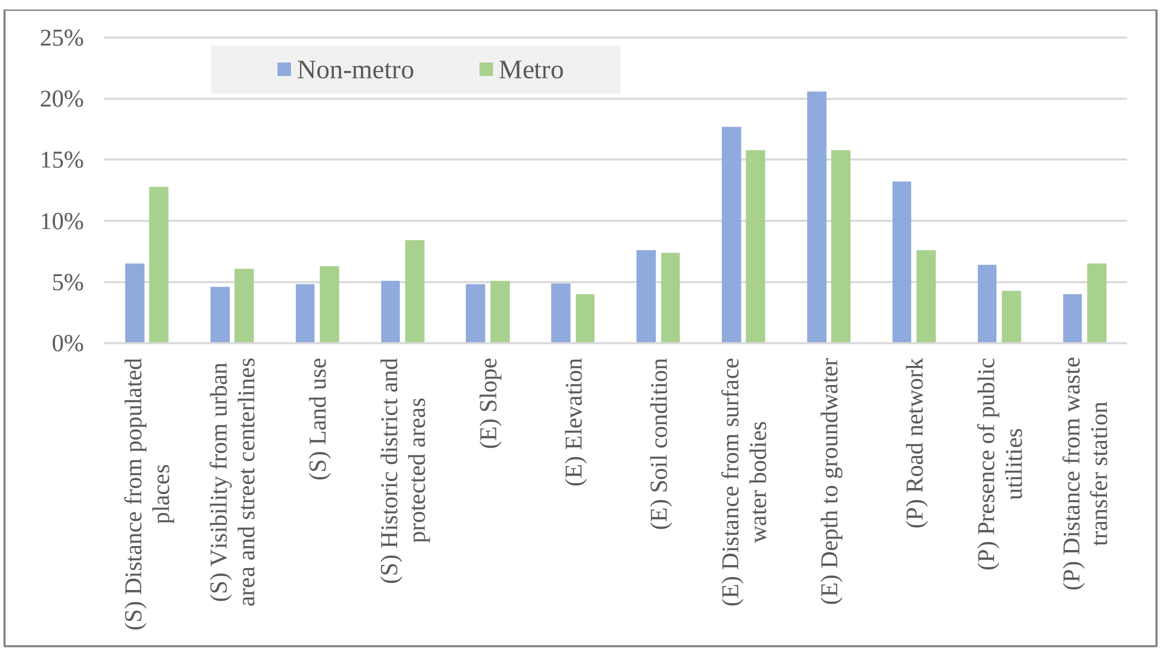
5.2. Analysis of factor weights by participants' location

Another notable result is related to the factor weights by the participants' location. A hypothesis regarding the results of the factor weights by the participants' location was that it would be different depending on the location where they work and live. For this analysis, Lincoln and Omaha were treated as a metropolitan and the rest of the counties in Nebraska were regarded as non-metropolitan. 14 out of 32 participants were located in the non-metropolitan areas while 18 participants were located in Lincoln and Omaha.

In the case of the metro group, the criteria, 'Distance from surface water bodies' and 'Depth to groundwater,' were assigned to the same rate as 15.8% on the highest of the ranking list. Similarly, those two criteria under the environmental factors placed first and second of the ranking with the weight of 20.6% (Depth to groundwater) and 17.7% (Distance from surface water bodies) respectively for the case of the non-metro group. Thus, it is probable that the environmental factors are likely to be considered as prior elements in both circumstances, and more in the non-metropolitan areas.

Moreover, it is noteworthy that the weights of all social factors of the metro group were higher than the non-metro group's weights as depicted in the left side of figure 8. It is also identified on the ranking list that the social factors are mainly considered in the metro group as presented in table 10. The 'Distance from populated places' (12.8%) and the 'Historic district and protected areas' (8.4%) criteria were included on the list of top 5 ranking of the metro group and are ranked higher. On the other hand, only the 'Distance from populated places' criterion was contained as a social factor on the non-metro groups' list with the weight of 6.5%, which was almost half of the metro group's factor weight, and the rest of the social factors' weights were less than 5%. The reason of this trend can be assumed which is that population density has had an impact. Thus, the density of population and the relative isolation from other people can influence the decision in relation to landfill siting, so people who are working or living within the rural areas have a higher possibility to consider the social factors less based on the results. Moreover, the suitability map by the participants' location based on the different factor weights are displayed in the figure 9. As mentioned in the previous paragraph, the metro group tends to think the social factor is important, accordingly, the areas of not suitable for the landfill (red color) is concentrated on the center of the county where the county seat is located.

Figure 8. Factor weight of criteria by participants' location



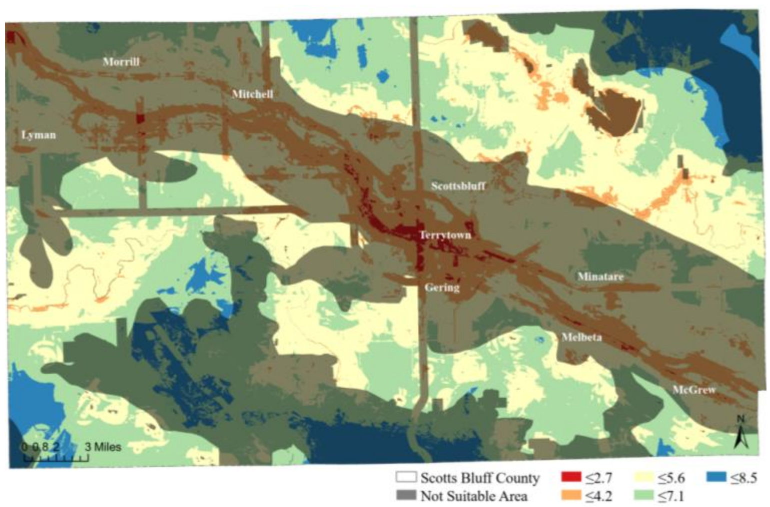
*(S) = Social factor, (E) = Environmental factor, (P) = Physical factor

Table 10. Top 5 ranking of criteria by participants' location

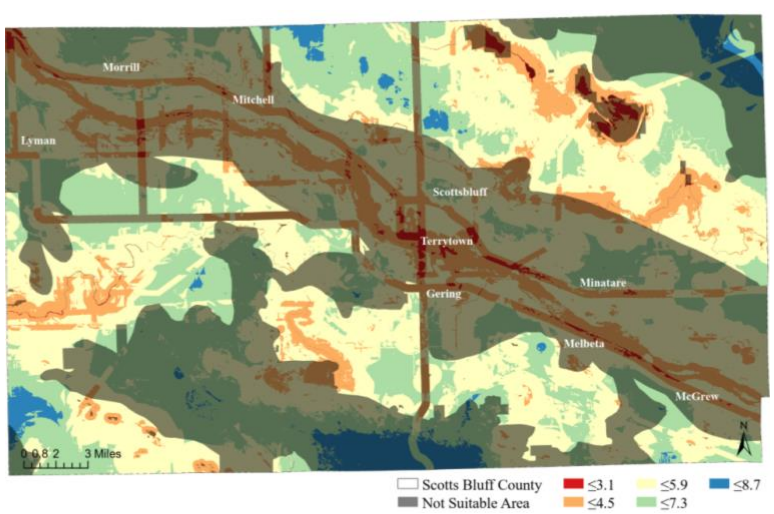
	Metro	**Non-metro**
1	(E) Distance from surface water bodies / Depth to groundwater	(E) Depth to groundwater
2	(S) Distance from populated places	(E) Distance from surface water bodies
3	(S) Historic district and protected areas	(P) Road network
4	(P) Road network	(E) Soil condition
5	(E) Soil condition	(S) Distance from populated places

* (S) = Social factor, (E) = Environmental factor, (P) = Physical factor

Figure 9. Suitability map by participants' location



(a) Metro group



(b) Non-metro group

5.3. Final factor weights using AHP

A hierarchy structure of the study consisted of three levels as described in chapter 3, methodology. Total four pair-wise comparisons were conducted to collect the judgements of the experts; accordingly, four pair-wise comparison matrices and the final priority vector (factor weight) of each criterion were derived from the application of the AHP methodology as demonstrated in table 11. 32 participants took part in the survey to share their judgements and the results for each criterion was averaged for use in the study and the final factor weight of each criterion were summarized in table 12 and figure 10.

According to table 11 (a), it turned out that the environmental factor is the most significant factor with a factor weight of 51.2% among the three factors. Using a nine-point scale (9, 8, 7, 6, 5, …, 1/5, 1/6, 1/7, 1/8, 1/9), where 9 point means absolute importance, 3 point means weak importance, and 1 point means equal importance, the environmental factor is 1.55 points more important than the social factor and 2.92 points more important than the physical factor. The consistency ratio of the matrix was 2.5%, which was less than 10%, so the result of the relative importance of the suitability criteria was reasonable to progress the analysis of sub-criteria of each factor.

‘Depth to groundwater’ criterion under the environmental factor ranked the highest as the most significant criterion with a weight of 17.7% as presented in Table 12 and figure 10. ‘Distance from surface water bodies’ and ‘Distance from populated places’ were the next most important criteria with a weight of 16.6% and 10% respectively. Conversely, the least significant criterion was ‘Elevation’ under the environmental factor, and it scored equal to 4.5%, which was only 0.5% less than the ‘Slope’ criterion. Environmental factors especially associated with water were overwhelmingly regarded as important elements among the criteria. Ground water and surface water are interconnected and when one of them becomes contaminated, it is difficult and expensive to restore. The U.S. Environmental Protection Agency (EPA) estimates that between 0.1% and 0.4% of usable surface aquifers are contaminated by industrial impoundments and landfills (Pedersen, 1997). Thus, it is worthwhile to note this finding that people perceived the fact that landfills influence surface and ground water condition.

Based on the judgements of the participants, table 11 (b) reveals that ‘Distance from populated places’ was considered as the most crucial criterion with a priority vector of 0.353 among the four social factors. On the other hand, ‘Visibility from urban area and street centerlines’ was scored 0.195 as the least important criterion. These two factors seem to be similar factors in relation to landfill issues, but the importance percentage of ‘Distance from populated places’ is almost twice that the percentage of ‘Visibility from urban area and street centerlines.’ Thus, the result of the importance of the social factor probably reflects an increase trend of odor problems at the landfill. Moreover, it is possible that landfill issues such as odors and blowing litter are usually regarded as more unacceptable problems than the issue of an unpleasant view because of the landfill. ‘Distance from historic district and protected areas’ ranked as a second important criterion with 0.252 point, which was an expected result.

As has been demonstrated in the previous paragraph, the most significant criterion was ‘Depth to groundwater’ among all criteria with the final weight of 0.177. Under the environmental factors, ‘Depth to groundwater’ and ‘Distance from surface water bodies’ were respectively assigned the priority vector of 0.346 and 0.323 as influential criteria as

Table 11. Results of the AHP application of the study

(a) Pair-wise comparison matrix of suitability criteria

Criteria	**Social**	**Environmental**	**Physical**	**Priority Vector**
Social	1	0.65	1.19	0.283
Environmental	1.55	1	2.92	0.512
Physical	0.84	0.34	1	0.204

· CR = 2.5% < 10%

(b) Pair-wise comparison matrix of social factors

Social Criteria	**(1)**	**(2)**	**(3)**	**(4)**	**Priority Vector**
(1)	1	2.10	1.59	1.33	0.353
(2)	0.48	1	1.09	0.79	0.195
(3)	0.63	0.92	1	0.81	0.201
(4)	0.75	1.27	1.23	1	0.252

(1) Distance from populated places (2) Visibility from urban area and street centerlines (3) Land use (4) Distance from historic district and protected areas

· CR = 0.5% < 10%

(c) Pair-wise comparison matrix of environmental factors

Environmental Criteria	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**Priority Vector**
(1)	1	1.32	0.65	0.26	0.29	0.099
(2)	0.76	1	0.60	0.30	0.27	0.087
(3)	1.55	1.67	1	0.48	0.38	0.145
(4)	3.78	3.38	2.09	1	0.94	0.323
(5)	3.41	3.70	2.66	1.06	1	0.346

(1) Slope (2) Elevation (3) Soil condition (4) Distance from surface water bodies (5) Depth to groundwater

· CR = 0.3% < 10%

(d) Pair-wise comparison matrix of physical factors

Physical Criteria	**(1)**	**(2)**	**(3)**	**Priority Vector**
(1)	1	2.30	1.42	0.475
(2)	0.44	1	1.18	0.256
(3)	0.70	0.85	1	0.269

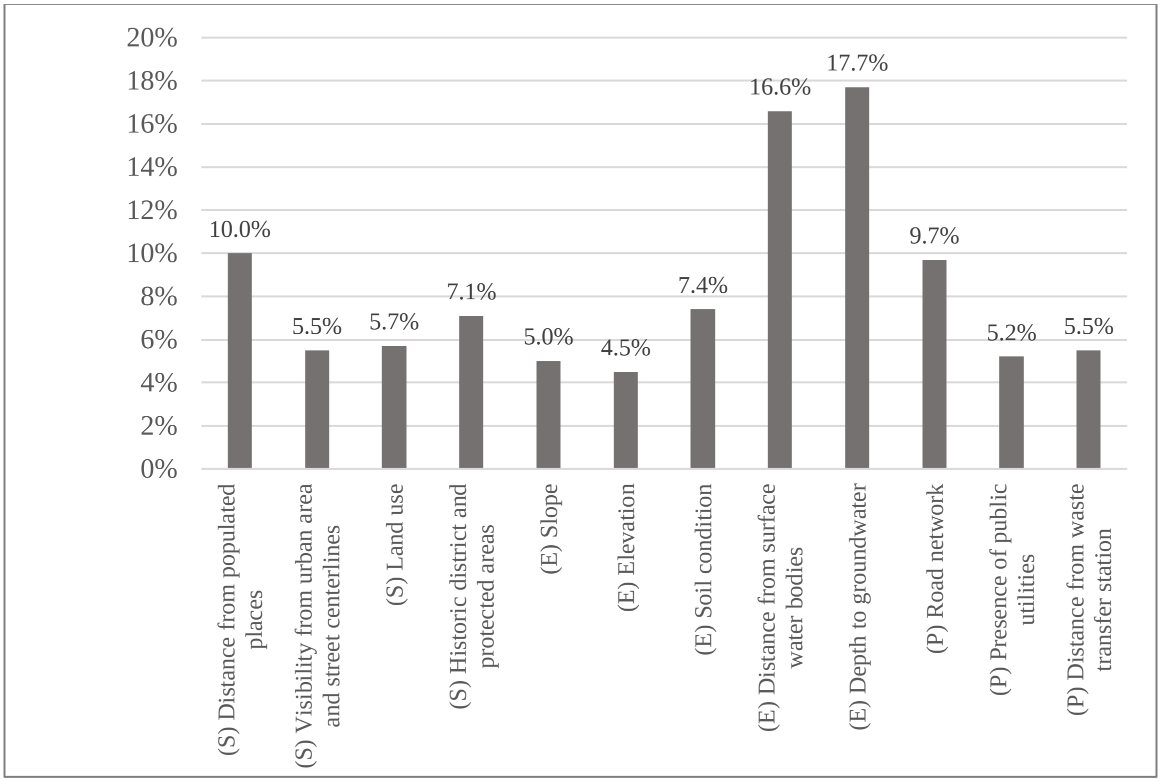
(1) Road network (2) Presence of public utilities (3) Distance from waste transfer station

· CR = 4.8% < 10%

Table 12. Final weight of each criterion

Category	**Priority Vector**	**Criteria**	**Priority vector**	**Final weight**	Ranking
Social factor	0.283	Distance from populated places	0.353	**0.100**	3
		Visibility from urban area and street centerlines	0.195	**0.055**	8
		Land use	0.201	**0.057**	7
		Historic district and protected areas	0.252	**0.071**	6
Environmental factor	0.512	Slope	0.099	**0.050**	10
		Elevation	0.087	**0.045**	11
		Soil condition	0.145	**0.074**	5
		Distance from surface water bodies	0.323	**0.166**	2
		Depth to groundwater	0.346	**0.177**	1
Physical factor	0.204	Road network	0.475	**0.097**	4
		Presence of public utilities	0.256	**0.052**	9
		Distance from waste transfer station	0.269	**0.055**	8

Figure 10. Consolidated results of final weight



* (S) = Social factor, (E) = Environmental factor, (P) = Physical factor

shown in table 11 (c). It could be interpreted that the risk of water contamination and connected environmental issues are highly recognized, and people think that a improper landfill site is likely to have a huge impact on this. The next most important criterion is 'Soil condition' with the priority vector of 0.145, and 'Slope' and 'Elevation' follow with a slight difference between the weights.

'Road network' criterion was considered as the fourth most significant component with the final weight of 9.7% based on the experts' judgement. Accordingly, the criterion ranked the highest among the three physical factors with 0.475 points. This criterion is related to economic aspects because well-established infrastructure will help to reduce additional costs such as transportation costs in constructing a landfill. However, landfill location should not interfere with the existing road network and traffic streams. Thus, it is essential to consider 'Road network' as a significant criterion along with others.

Another notable finding about the judgements of factor weights was about the group consensus. The software that was used for the study to conduct the AHP methodology provided a group consensus value which is an estimate of the agreement on the outcoming priorities between participants (Goepel, 2018). It was categorized into five groups based on the range between 0% and 100%, and the indicator is as follows: Very low consensus (below 50%), Low consensus (50 - 65%), Moderate consensus (65 - 75%), High consensus (75 – 85%), Very high consensus (above 85%). According to Goepel (2018), the concept of diversity based on Shannon alpha and beta entropy was applied to produce the indicator. Thus, it is a measure of homogeneity of priorities between the participants and can also be interpreted as a measure of overlap between the priorities of the participants (Goepel, 2018).

Based on the indicator, the group consensus of the social, environmental, physical factors was respectively derived as 53.4%, 72.1%, and 66.4%. The group consensus of the environmental factors was the highest, which was regarded as moderate consensus, and the consensus of the social factor was the lowest, which was regarded as low consensus. It can be assumed that the social factor in relation to landfills is more complex and it is difficult to resolve differences among diverse people's opinions than the environmental and the physical factor. People's thoughts regarding the social factor are especially variant and it depends highly on their perception and beliefs, so creating a consensus decision about social factors in relation to landfill is such a complicated issue compared to the other factors. On the other hand, the environmental factors about landfills are commonly accepted by people because of its widespread impacts.

5.4. Final suitability map based on final factor weight

As the result, the final suitability map as shown in figure 11 was produced by applying the different factor weights, and the constrained areas were overlapped as the black zones based on the federal and local regulations of landfill locational criteria. The range of the landfill suitability index was classified into 5 groups between 1.66 to 8.63 using an equal interval data classification method in ArcGIS Pro software. The class breaks of equal interval were determined based on the range of attribute values into equal-sized subranges (Esri, ArcGIS Pro, n.d.). Thus, the study area was displayed based on 5 classes as shown in figure 11: Very low suitability (1.65-3.05), Low suitability (3.06-4.44), Moderate suitability (4.45-5.84), High suitability (5.85-7.23), Very high suitability (7.24-8.63). According to the results, 11.4% of the study area, with an actual size of approximately 220 km^2, has lower suitability including very low suitable and low suitable areas, while 46.2% of the study area has moderate suitability for the landfill and the actual size of this area is approximately 890 km^2. Subsequently, 35.4% of the study area is highly suitable with a size of 680 km^2. However, only 6.9% of the county, approximately 130 km^2 has very high suitability for the landfill sites.

Since the North Platte River flows east southeastward through the upper central part of the county, the areas not suitable for landfill are spread northwest and southeast around the river. The communities of the county, including Morrill, Mitchell, Scottsbluff, Terry Town, Gering, Minatare, Melbeta, and McGrew are also located along the river. Accordingly, the areas of low suitability and very low suitability tended to be concentrated in the surrounding areas. Unfortunately, half of the areas otherwise considered very suitable for landfills are constrained by the landfill locational regulations because those areas contain steep bluffs and escarpments, valleys, and protected area such as Scotts Bluff National Monument and Wildcat Hills State Recreation Area.

On the other hand, figure 12 describes the final suitability map without the factor weight in order to compare the difference with the suitability map with the factor weight. The map of figure 12 was produced by equally applying a weight to the 12 criteria. The map was also classified into 5 groups; Very low suitability (2.24-3.46), Low suitability (3.47-4.67), Moderate suitability (4.68-5.89), High suitability (5.90-7.10), Very high suitability (7.11-8.32), but the range of the landfill suitability index was between 2.24 to 8.32 using an equal interval data classification method the same as the map of figure 11. Consequently, it is clear that the map without the factor weight is presenting relatively more areas of high suitability. According to the results, only 4% of the area has lower suitability, with a land size of approximately 77km^2, whereas the map with the factor weight has 11.4% of lower suitable areas. Furthermore, the result shows that almost 57% of the study area has high suitability for the landfill sites, which is over the half of the actual land size. Therefore, it is possible to say that weighting each factor based on experts' judgement using AHP methodology is significant in the decision-making process of landfill siting and it was properly applied for the study to identify the landfill suitability in the study area.

As the final outcome, figure 11 indicates potential candidate sites on the map. A total of eight candidate sites (a ~ h) were identified, and their specific information is described in table 13 such as accessibility, land use, and distance from the existing communities. All candidate sites were regarded as areas having very high suitability for the landfill based on the factor weight and the grading structure. They are also located in areas where they are accessible to the current road network and most of them have a fair distance from populated places and the surface water bodies such as ponds, lakes, and rivers within the study area. The largest landfill in the U.S. is Puente Hills Landfill in southeastern Los Angeles County near Whittier, California, covering approximately 700 acres (2.8 km^2), and the average landfill size in the U.S. is between 300 acres (1.2 km^2) to 600 (2.4 km^2) acres. The current landfill in the study area is covering approximately 33.5 acres (0.1 km^2). Thus, all the candidate sites area large enough to fairly use for the landfill, especially candidate sites (a), (b), (c), (f), and (g) are appropriate in terms of the area size. However, the land size for the landfill needs to be considered based on expected waste amount that the landfill is planning to accept and the size of the community that the landfill is planning to service.

Figure 11. Suitability map with factor weight

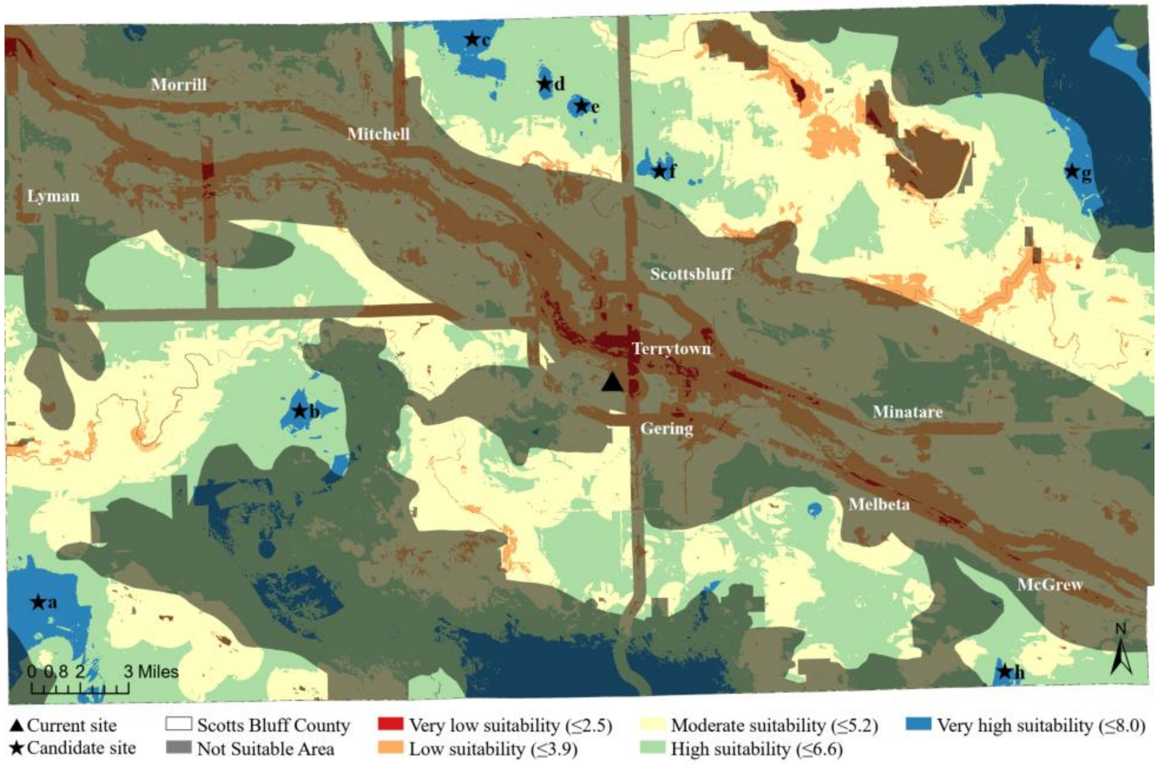


Figure 12. Suitability map without factor weight

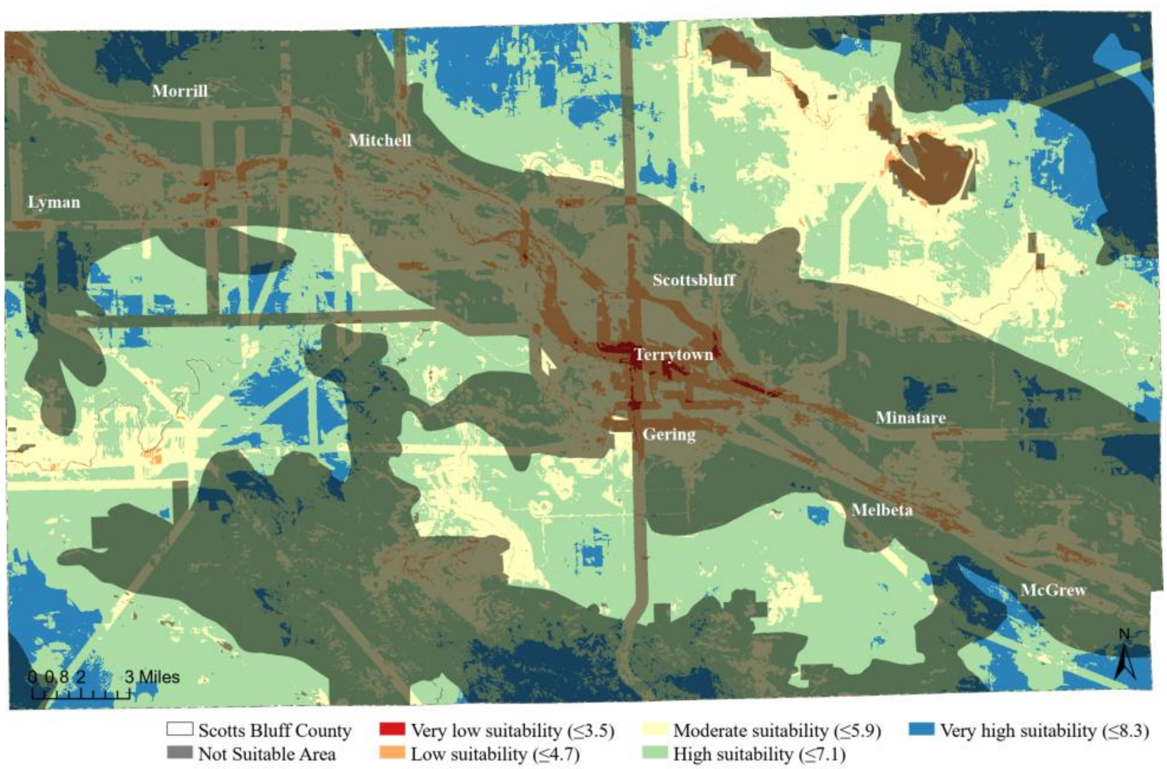


Table 13. Several information of the final candidate sites for the landfill

Candidate site	**Area**	**Distance from populated places**	**Distance from surface water**	**Accessible to road**	**Land use**
(a)	13.5 km^2	17.2 km	2.5 km	O	Summer fallow, Range, Pasture, Grass
(b)	2.7 km^2	12.9 km	2.7 km	O	Summer fallow, Range, Pasture, Grass
(c)	6.9 km^2	6.1 km	3.9 km	O	Range, Pasture, Grass, Irrigated corn
(d)	0.9 km^2	7.8 km	2.7 km	O	Irrigated corn, Range, pasture, grass, Dryland corn
(e)	1 km^2	9.2 km	6.6 km	O	Range, Pasture, Grass
(f)	1.6 km^2	6.9 km	2.4 km	O	Range, Pasture, Grass, Dryland corn
(g)	4.6 km^2	15.8 km	5.8 km	O	Irrigated corn, Summer fallow, Range, Pasture, Grass
(h)	1.1 km^2	7.6 km	2.1 km	O	Range, Pasture, Grass, Summer fallow

The candidate site (b) has enough distance from populated places and surface water bodies, but the surrounding areas have a particularly rugged landscape and steep terrain compared to other candidate sites. The candidate site (f) has proper distance from the existing road network and the location is not too far from the center of the city, however, several houses are concentrated within the area compared to other candidate sites. The area of the candidate site (g) is pretty large for the landfill, but the location is too close to the exclusionary zone and the elevation of the surroundings drastically changes, which is inappropriate for landfill construction. Therefore, the candidate sites (a) and (c) would be the most suitable for the landfill based on the various considerations and the evaluation of the study.

Chapter 6 Conclusion

6.1. Planning Implications

The management of municipal solid waste (MSW) is becoming a major concern that is faced by municipal authorities, city planners, and decision-makers due to limited resources, increasing population, and industrialization (Hazra & Goel, 2009). The solid waste disposal function is becoming more regionalized because of the growth and densification of suburban municipalities. This trend is in part due to the difficulty of finding new disposal sites, and it often leads to unsuccessful siting processes and serious community opposition against the facility. The problems are more serious in various countries where the unscientific method of solid waste management is practiced due to various issues such as industrialization and the poor perception of human awareness. This could generate a huge quantity of solid waste but also contribute to inappropriate dumping of such waste which is now a key environmental challenge faced by humanity. The two most important things when developing procedures to search for a landfill sites and actually siting a landfill are whether regulatory agencies will approve the location and whether the public will accept it (StinnettDebra, 1996). Therefore, proper site search processes and detailed investigations will be needed to reduce negative impacts on the host community and environmental risk. Additionally, much more research and work will need to be done and multiple factors of internal and external challenges should be considered in various perspectives.

One of the most controversial planning issues is the siting and management of solid waste handling facilities in local contexts, because it produces environmental and health problems, and the way we design and handle has both positive and adverse effects on surrounding communities. Furthermore, these kinds of studies could be enlarged to siting other unpleasant infrastructure in communities. Getting public involvement in the site search process of unpleasant infrastructure in communities is recommended. Otherwise, it leads to potential litigation and other time-consuming and costly delays due to strong public opposition. The EPA and many others recommend getting the public involved earlier in the siting process. Thus, a well-run public involvement process should increase acceptance for a proposed landfill or unpleasant infrastructure rather than generate opposition. As a result, a clear understanding of regulatory criteria, public opinion and involvement, and detailed investigations should be used in harmony to site unpleasant infrastructure in the most suitable and acceptable area in the communities.

6.2. Limitations

Based on the limited data available, the final weights using AHP methodology were calculated, the analysis of factor weights by the different participants' groups were completed, and the final suitability GIS maps were produced for the study. As with every research, it is important to have a sufficient sample size in the beginning stages of the research to conduct a study and derive reasonable and valid research results. However, there was a limitation regarding insufficient sample size for statistical measurement for this study. Only 32 participants were able to take part in the survey with a 17.8% response rate. Accordingly, the analysis and the results can be questioned, based on the number of participants. Fortunately, the survey response was received from the experts in the different fields, and its proportion was fairly allocated, which made it possible to use the average value of each group when analyzing the difference of the factor weights by the participants' group. It is true that the larger the sample size, the more precise results will be. Thus, the results cannot be generalized to every situation, but the survey results of this study were quite enough to identify important relationships from the data. If there was a larger sample size of the experts from much diverse fields, not only would the study provide different results but also the analysis of the study would be interpreted through more diverse viewpoints.

Additionally, the study was completed by categorizing the participants in four groups: planner, engineer, landfill staff, and environmental official. However, there are a number of stakeholders and related experts in relation to landfills. Thus, the results of the study can be limited in the perspective of the given participant groups. Furthermore, one's political orientation, cultural background, and personal experience can have a huge impact on the judgement of each participant. Therefore, as a limitation this is one of the nonnegligible parts.

The other limitation was associated with the criteria. A total of 12 criteria were applied for the study; however, identifying influenced criteria and categorizing then into different hierarchical levels such as social, environmental, economic, and technical was not a simple process. As mentioned in Chapter 4, those criteria are organically related to each other, and no single set of criteria and categories exists for the landfill siting process that can apply to all regions and situations. Because of this, there might have been a lack of analysis regarding criteria and categories in relation to landfills. Hence, there can be a deficiency of other viable perspectives in the process of deciding factors. The criteria used for the study might have been biased due to the researcher's backgrounds and views, and it could have impact on the hypotheses or arguments of data analysis. For example, in the 'Depth to groundwater' criterion under the environmental factors, the method used to calculate its depth could derive some error. According to the expert of groundwater condition, the depth to the water table can change (rise or fall) depending on the time of year. During the late winter and spring when accumulated snow starts to melt and spring rainfall is plentiful, water on the surface infiltrates into the ground and the water table rises. Conversely, when water-loving plants start to grow again in the spring and precipitation gives way to hot, dry summers, the groundwater table falls because of evapotranspiration. Additionally, different aquifers are not connected and highly variable. Thus, the nature of the local geology and aquifer properties are much more important, and it is not an easy process to calculate depth to groundwater. Therefore, it will be essential to get advice from associated experts before deciding the criteria and its standards. Based on such limitations, the criteria for the study were selected based on the common elements as much as possible and chosen from the list of higher priorities.

Lastly, there is a limitation that the analysis was not conducted for the adjacent counties of the study area such as Sioux, Box Butte, Morrill and Banner Counties in Nebraska and Goshen county in Wyoming. When producing a final suitability map, it is important to identify as much data of the study area as possible in order to understand its geographical information and other community features. Since several components such as geography, hydrography, and road network are connected across the state, it is necessary to analyze the adjacent counties' situations and circumstances. Thus, a lack of studies for the surrounding counties will work as a limitation for the study. Fortunately, any considerations that can influence the analysis of the study area were not found based on the Google map view, but there is a possibility that some environmental factors would vary compared to the study area and unexpected factors can be raised. Because of this limitation, analysis of adjacent surroundings of a study area need to be completed after deciding the area for study.

6.3. Conclusion

Landfill site selection is a complicated process to accomplish and substantial number of considerations should be contemplated in order to identify the best location which is highly suitable within an area. However, it is a difficult task to find a point of compromise with balancing socio-economic, environmental, and technical perspectives. Moreover, identifying proper locations for municipal solid waste is becoming a great challenge due to population growth, urbanization, farmland preservation and complex problems from landfills. Potential issues and even unexpected problems can be raised in relation to landfill placement: Environmental and health risks such as air quality issues and potential water contamination concerns, economic issues such as the impact of landfill construction on local industry, social issues such as community protests based on equity in site choice, and political issues such as landfill and its surrounding management responsibility.

Hence, landfill suitability assessment should be conducted with understanding of various factors and with respect to the decision objectives. Analytic Hierarchy Process (AHP) methodology will support the decision-making process to gain better results. Before using the AHP, selection of criteria that influence landfill placement first needs to be completed based on various perspectives in relation to landfill and its management. There are a number of stakeholders and experts who are interested in this issue. Thus, the feasibility of each criterion and the validity of its explanation should be identified. Not all possible decision criteria are equally important, accordingly, the criteria need to be weighted based on the judgements of experts and stakeholders using AHP. Furthermore, GIS will help to visualize the process and find the final suitable sites for the landfill. As described in this study, weighting each criterion for landfill placement is significant to get more reasonable results than considering them without the weights. As a result, a clear understanding of regulatory criteria, possible considerations, and various impacts in relation to the landfill is essential when developing procedures to search for a landfill site.

Appendix A. IRB Approval letter

Nebraska UNIVERSITY OF Lincoln

Official Approval Letter for IRB project # 20639 - New Project Form
September 22, 2020

Sunah Moon
Community and Regional Planning Program
ARCH 210 UNL NE 685880106

Yunwoo Nam
Community and Regional Planning Program
ARCH 314 UNL NE 685880105

IRB Number: 20200920639EX
Project ID: 20639
Project Title: Landfill site suitability assessment using integrated GIS and AHP

Dear Sunah:

This letter is to officially notify you of the certification of exemption of your project for the Protection of Human Subjects. Your proposal is in compliance with this institution's Federal Wide Assurance 00002258 and the DHHS Regulations for the Protection of Human Subjects at 45 CFR 46 2018 Requirements and has been classified as exempt. Exempt categories are listed within HRPP Policy #4.001: Exempt Research available at: http://research.unl.edu/researchcompliance/policies-procedures/.

o Date of Final Exemption: 9/22/2020
o Certification of Exemption Valid Until: 9/22/2025
o Review conducted using exempt category 2(ii) at 45 CFR 46.104
o Funding (Grant congruency, OSP Project/Form ID and Funding Sponsor Award Number, if applicable): N/A

We wish to remind you that the principal investigator is responsible for reporting to this Board any of the following events within 48 hours of the event:
* Any serious event (including on-site and off-site adverse events, injuries, side effects, deaths, or other problems) which in the opinion of the local investigator was unanticipated, involved risk to subjects or others, and was possibly related to the research procedures;
* Any serious accidental or unintentional change to the IRB-approved protocol that involves risk or has the potential to recur;
* Any protocol violation or protocol deviation
* An incarceration of a research participant in a protocol that was not approved to include prisoners
* Any knowledge of adverse audits or enforcement actions required by Sponsors
* Any publication in the literature, safety monitoring report, interim result or other finding that indicates an unexpected change to the risk/benefit ratio of the research;
* Any breach in confidentiality or compromise in data privacy related to the subject or others; or
* Any complaint of a subject that indicates an unanticipated risk or that cannot be resolved by the research staff.

This project should be conducted in full accordance with all applicable sections of the IRB Guidelines and you should notify the IRB immediately of any proposed changes that may affect the exempt status of your research project. You should report any unanticipated problems involving risks to the participants or others to the Board.

If you have any questions, please contact the IRB office at 402-472-6965.

Sincerely,

Rachel Wenzl, CIP
for the IRB

Association for the Accreditation of Human Research Protection Programs, Inc. Full Accreditation

University of Nebraska-Lincoln Office of Research and Economic Development
nugrant.unl.edu

NUgrant

Appendix B. Introductory Email

Survey Introductory Email

Hi,

My name is Sunah Moon and I am a graduate student in Community and Regional Planning in University of Nebraska Lincoln.

I am sorry for suddenly reaching out to you. I am currently working on my thesis focusing on landfill site selection by using geographic Information System (GIS) and Analytic Hierarchy Process (AHP).

The objective of the research is to identify potential landfill sites based on key considerations including local and EPA landfill location requirements. Moreover, some social, environmental, and physical factors that influence in a siting process of landfill will be applied as the evaluating criteria. Thus, this study will reinforce the process of deciding the importance of the evaluating criteria, and I would like to get opinion from people who are related to the topic. So, I thought it would be good to get opinions from the people such as planner, engineer, and landfill operator who are associated in a decision-making process when siting a landfill in a community.

Therefore, I was wondering whether you are willing to do a short online survey. It will take under 5 minutes, and your answer will help me to develop various perspectives, identify the relative importance of each criterion, and meet better results for the research. Your name and other information such as email address will not be revealed in the project paper and only the researcher (Sunah Moon) will see the result. The link is as follows: https://bpmsg.com/ahp/ahp-hiergini.php?sc=zAhatu. I have also attached a short description about each criterion and the instruction to do the survey, so please check it.

I believe that this research is going to help to develop some ways to minimize environmental and health risks in relation to the landfill by taking social, environmental, and physical factors into account when identifying the suitable areas for landfill. Moreover, I believe that it is related to other unpleasant infrastructure siting process. Please share with me your opinion on landfill suitability. If you have additional idea regarding landfill suitability criteria, please let me know. It will be very helpful.

If you have questions about the research and the survey, please do not hesitate to contact me by email or phone. Thank you for your time. I will wait for your reply.

Best,
Sunah Moon
Graduate Research Assistant
Community and Regional Planning
University of Nebraska-Lincoln
Email: sunah.moon@huskers.unl.edu
Phone: 402-708-8828

Appendix C. Survey Questions

Please do the pairwise comparison of all criteria.

1. Check the box of one factor between two factors that you think more important.
2. Check the box on a scale that how much more the factor that you checked is important.

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

---

1. With respect to landfill suitability, which criterion is more important, and how much more on a scale 1 to 9?

A – with respect to Landfill suitability – or B?			Equal	How much more?
1	☐ Social factor	☐ Environmental factor	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
2	☐ Social factor	☐ Physical factor	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
3	☐ Environmental factor	☐ Physical factor	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

Landfill Suitability	Social Factor	Distance from populated places
		Visibility from urban area and street centerlines
		Land use
		Distance from historic district, protected and recreation area
	Environmental Factor	Slope
		Elevation
		Soil condition
		Distance from surface water and groundwater sources
		Depth to groundwater
	Physical Factor	Road network
		Presence of public utilities
		Distance from waste transfer station

2. With respect to *Social factor*, which criterion is more important, and how much more on a scale 1 to 9?

A – with respect to Social factor – or B?			Equal	How much more?
1	☐ Distance from populated places	☐ Visibility from urban area and street centerlines	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
2	☐ Distance from populated places	☐ Land use	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
3	☐ Distance from populated places	☐ Historic district, protected and recreation areas	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
4	☐ Visibility from urban area and street centerlines	☐ Land use	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
5	☐ Visibility from urban area and street centerlines	☐ Historic district, protected and recreation areas	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
6	☐ Land use	☐ Historic district, protected and recreation areas	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

Distance from populated places

Siting municipal solid waste landfill close to populated places causes not only many environmental problems but also public complaints. Thus, proper distance of potential landfill sites from residential areas should be significantly considered. It is outlined in Title 132 – Nebraska Department of Environmental Quality, Chapter 3 (002.02E) – that the landfill application should include a description of the population density of the proposed facility and of the area surrounding the facility within one mile of the facility boundaries.

Land use

Land use show how people use the landscape whether for developments, conservation, or mixed uses. Current land use affect landfill placement with urban sprawl, farmland preservation, and population growth. Therefore, planned future development and improper areas should be excluded in the siting process.

Visibility from urban area and street centerlines

Visual contact with residential areas and street centerlines would be considered to increase community complaints because of unpleasant view and other potential negative impacts in relation to the landfill. When existing landfill considers a landfill expansion, they often conduct a visual assessment of the development whether the proposed landfill expansion will significantly impact the surrounding properties and community.

Historic district, protected and recreation areas

Historical/archeological sites and recreation areas should be avoided in locating a landfill. Because developing a landfill in one of these areas can damage the environment and impede a successfully operated landfill, siting a landfill within monumental or recreational areas need to be forbidden.

3. With respect to *Environmental factor*, Which criterion is more important, and how much more on a scale 1 to 9?

A with respect to Social factor or B?			Equal	How much more?
1	☐ Slope	☐ Soil condition	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
2	☐ Slope	☐ Distance from surface water/groundwater resources	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
3	☐ Slope	☐ Depth to groundwater	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
4	☐ Slope	☐ Elevation	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
5	☐ Soil condition	☐ Distance from surface water/groundwater resources	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
6	☐ Soil condition	☐ Depth to groundwater	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
7	☐ Soil condition	☐ Elevation	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
8	☐ Distance from surface water/groundwater resources	☐ Depth to groundwater	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
9	☐ Distance from surface water/groundwater resources	☐ Elevation	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
10	☐ Depth to groundwater	☐ Elevation	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

Slope & Elevation

Slope of land surface is an essential factor to consider in the landfill siting process because steep slopes will lead to higher excavation costs for construction and retention. The slope of the land surface will be calculated on the pixel basis using the digital elevation model (DEM) of the study area. Elevation is another main parameter to be considered in the landfill siting decision with slope. High elevation is inappropriate for landfill sites because it causes difficulties during construction while too low elevation would have ana impact on runoff drainage.

Soil Condition (Soil hydric class, soil flooding frequency, soil erodibility factor, etc.)

Soil condition can provide useful information in the landfill location siting process. For example, permeable soils will provide less protection and may require installing additional controls within the landfill. Thus, soil hydric class, soil erodibility factor, and soil flooding frequency would be contemplated together to measure general soil condition.
* Soil hydric class: Hydric soils are soils that form under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part of the soil.
* Soil Erodibility Factor: It represents both susceptibility of soil to erosion and the rate of runoff. Erodibility factor is a value between 0 and 1. If values of K for soils is greater than 0.4, it tends to crust and produce high rates of runoff.
* Soil flooding frequency: Soil flooding frequency provides an estimate of the likelihood of flooding in a given year.

Distance to surface water and groundwater sources

According to Title 132 – Nebraska Department of Environmental Quality, Chapter 3 (002.01), a landfill site should not be located in an area where the solid waste activities will have a detrimental effect on the waters of the state. Because a landfill site which is adjacent to any water sources can cause potential pollution, certain distance of buffer zone should be maintained around significant water bodies.

Depth to groundwater

It is described in Title 132 Nebraska Department of Environmental Quality, Chapter 3 (002.01B) - that areas having high ground water tables may be restricted to landfill operations which will maintain a safe vertical distance between deposited refuse and the maximum water table elevation. Moreover, it will influence design features of landfill, such as leachate collection and liner requirements.

4. With respect to *Physical factor*, Which criterion is more important, and how much more on a scale 1 to 9?

	A with respect to Social factor	or B?	Equal	How much more?
1	☐ Road network	☐ Presence of public utilities	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
2	☐ Road network	☐ Distance from waste transfer station	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
3	☐ Presence of public utilities	☐ Distance from waste production center	☐ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

Road network

The criterion of distance from road network should be taken into account for the selection of suitable landfill site because it represents the greater or lesser accessibility to the site itself. If the potential sites are located too far from the existing road network, it is inevitable to face excessive costs for the construction of connecting roads. However, according to Title 132 Nebraska Department of Environmental Quality, Chapter 3 (002.03), a solid waste disposal area should not be located within 1,000 feet from the nearest edge of an existing right-of-way of any state, interstate or federal highway. Therefore, a comprehensive criterion in relation to road network is needed.

Distance from waste transfer station

Distance from potential landfill sites to solid waste transfer station influences transportation costs. It is significantly related to the economic feasibility of a candidate landfill site. However, some waste production center is located within urban areas and populated places, so it should be discussed as one of the important criteria.

Presence of public utilities

The presence of public utilities such as electricity in the proper proximity of the potential landfill sites is important factor to consider. The absence of such utilities would generate additional costs to develop and operate solid waste disposal.

Thank you for your participation!

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