CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING METHODS TO EVALUATE WASTE MANAGEMENT REGIONS IN NOVA SCOTIA

Richter, A.[1], Bolingbroke, D.[1], and Ng, K.T.W.[1,2]
[1] Environmental Systems Engineering, University of Regina
[2] Kelvin.Ng@uregina.ca

Abstract: The average Nova Scotian generated 682 kg of non-hazardous waste in 2014 and diverted 43.4%; while the average Canadian generated 961 kg/cap in 2014, and only diverted 26.5%. GIS (Geographic Information Systems) approaches have been widely used to site waste conversion facilities and landfills and remote sensing (RS) may help to further facilitate data-driven landfill siting. As a result, GIS and RS techniques can be integrated and used to assess the location of current landfills in relation to infrastructure, population and other biophysical indicators. The objectives of this study are to: (i) gather and combine vector data (road network, population location, and waste facility location) with RS indices (vegetation, built-up area, and moisture) in a GIS, and (ii) rank and assess Nova Scotia's seven waste management regions based on a normalized ranking classification. The GIS-based approach will combine vector data with RS data using ArcGIS Zonal Statistics and other vector analysis tools to provide a ranked map of each of Nova Scotia's seven waste management regions. The analysis revealed that 26.7% of the province ranked well in terms of the environmental impact of solid waste management, while 38.5% ranked moderately, and 34.8% ranked poorly. It is believed that this research will provide information planners and policy makers in provinces that are moving towards regionalization of waste management facilities.

1 INTRODUCTION & LITERATURE REVIEW

Since the development and implementation of Nova Scotia's Solid Waste Resource Management Strategy, the province has been successful in increasing diversion rates to the highest in Canada over a 20-year period (Statistics Canada, 2019). In 1995, Nova Scotia developed their Solid Waste Resource Management Strategy (Government of Nova Scotia, 1995), which proposed seven waste management regions (WMRs). This came after consultations on solid waste and an understanding that establishment of efficient regions for waste management was imperative (Government of Nova Scotia, 1995). There are currently approximately 9.4 landfills per million people in Nova Scotia, but about 86.0 waste management facilities per million people. In this paper, waste management facilities refer to: asbestos treatment facilities, construction & demolition facilities, household hazardous waste facilities, organic composition facilities and recycling facilities. The difference between the number of landfills and other types of waste management facilities reflects the province's move towards an integrated waste management system.

Richter et al. (2017) studied expenditure and business characteristics of waste management in Nova Scotia (NS) and used linear regression to investigate the relationship between the two. The study suggested that higher spending in NS may be responsible for improved diversion, and that the allocation of money to different areas of the solid waste management system may help in the development of a more sophisticated waste management system. Richter et al. (2018) confirmed that differences in percent of operating expenditure to different areas of solid waste management may be responsible for higher diversion, and that in NS multiple linear regression modelling had a higher accuracy than other areas studied. The study concluded that investment in organic processing facilities are vital for promotion of increased recycling and diversion rates.

The use of remote sensing (RS) and geographic information system (GIS) techniques can be useful to various aspects of landfill management, including siting of landfills, detection of illegal disposal sites, and studies on contamination near landfills (Faisal, 2011). Recent applications of the techniques within solid waste management range from management of construction and demolition waste in war-stricken environments (Madi and Srour, 2019) to landfill siting (Alexakis and Sarris, 2014; El Maguiri et al., 2016) to applications directly at the landfill (Mahmood et al., 2016, 2017; Manzo et al., 2016, 2017).

Manzo et al. (2016) integrated multi- and hyper-spectral RS data to study the consecutive impact of mining and disposal of solid waste in an area southeast of Mount Vesuvius National Park, Italy. Normalized Difference Vegetation Index (NDVI) was used for change detection in the study. The use of coarse RS imagery was used to characterize the environmental condition, and the hyperspectral data was used to provide information on cover changes in the area. According to the authors, the results are vital for the planning of chemical field surveys and monitoring of vegetation in the area.

Manzo et al. (2017) studied a controlled landfill site in the Vetrano locality in Calabria, Italy. Change detection was carried out on both NDVI and GEMI (Global Environmental Monitoring Index). This data was then combined with in-situ measurement of atmospheric pollutants and thermal survey imagery. All of this data was combined in a top-down approach and was used to identify environmental points of interest. The study suggested that while RS cannot substitute chemical analysis, it can help to identify points of interest. The authors also suggested that RS may be a basic step towards a ‘smart’ landfill.

Mahmood et al. (2016) used 4 different RS indices in spatio-temporal analysis to develop a boundary of bio-thermally affected zones around landfills. Results showed there was a permanent average temperature of 4.3 K above surrounding agricultural lands, and an average increase of 2.78 K from urban areas. The temperature elevation around the landfill was found to be purely due to bio-chemical degradation of municipal solid waste in the dump. Furthermore, the results confirm that indices such as NDVI (Normalized Difference Vegetation Index), SAVI (Soil-Adjusted Vegetation Index), and MSAVI (Modified Soil-Adjusted Vegetation Index) are effective bio-indicators in this study.

In their 2017 study, Mahmood et al. (2017) used the same indices (NDVI, SAVI, MSAVI) to find an area of influence around 2 open dumping sites in Lahore and Faisalabad, Pakistan. The study showed that dumping sites had a thermal influence of about 650 m in radius. According to the authors, MSAVI was the best index to use, since it was able to account for soil reflectance.

Whereas most studies are focused on the use of RS to either site landfills, study landfills and their surroundings, or aid in the environmental monitoring of landfills, this study combines GIS, vector data and RS to rank Nova Scotia’s WMRs. The objectives of this study are to (i) gather and combine vector data (road network, population location, and waste facility location) with RS indices (vegetation, built-up area, and moisture) in a GIS, and (ii) rank and assess Nova Scotia’s seven WMRs based on a normalized ranking classification. It is believed that the findings from this study may help to optimize Nova Scotia’s WMRs as well as providing information to other policy makers in areas where regionalized landfilling is being considered.

2 METHODOLOGY

2.1 Study Area

Figure 1 shows the study area (Nova Scotia), and its seven WMRs. Nova Scotia is located on the eastern seaboard and is one of Canada's Maritime Provinces. The province had an estimated population of 954,000 people in 2017 (Statistics Canada, 2018). The largest city in the study area is Halifax, located in the Halifax Regional Municipality (HRM), accounting for 46.2% of the province's population (Statistics Canada, 2018).

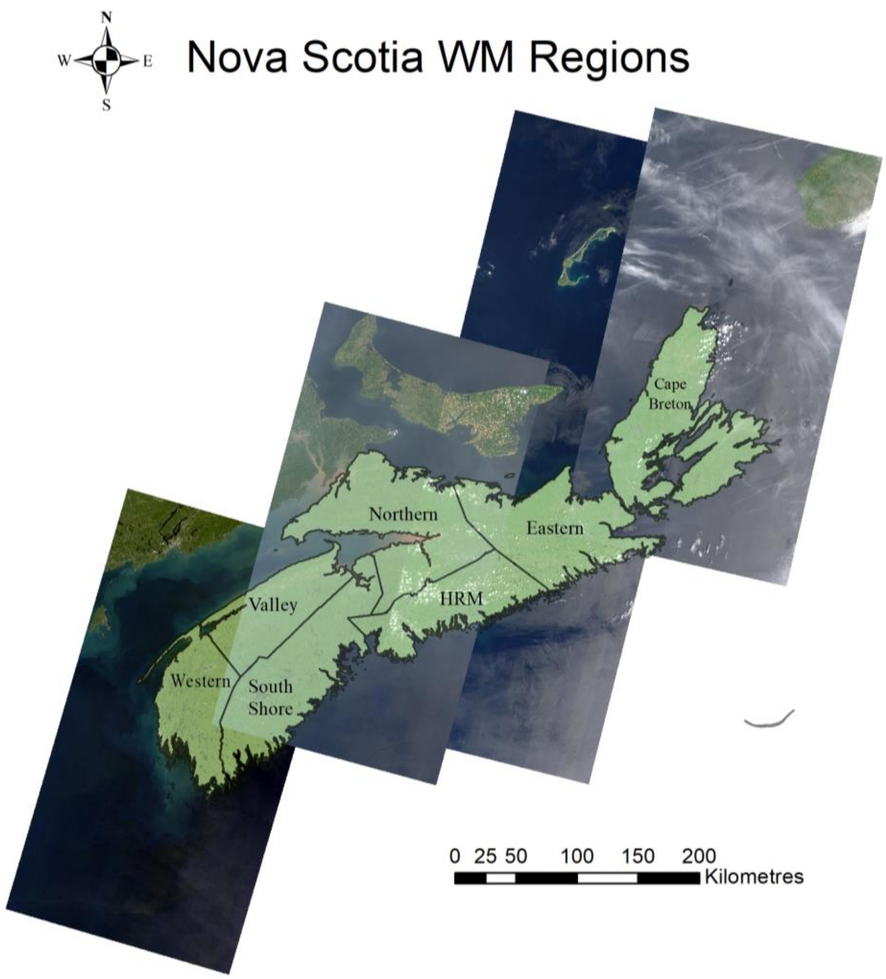

Figure 1: Study area (Nova Scotia) and its 7 waste management regions (Source: USGS)

2.2 RS Data Acquisition

Between July and September 2017, 9 Landsat scenes (L1T) were used to create a mosaic of the study area. Landsat images were acquired from the United States Geological Survey (USGS) using Earth Explorer (https://earthexplorer.usgs.gov/). Data from paths 6, 7, and 8 and rows 27, 28, 29, and 30 covered the study area. Mosaicking was completed using the Data Management Toolbox and the Mosaic to New

Raster Tool in ArcGIS v. 10.5.1. The mosaic operator was set to max and the colormap was set to Match. Band Quality Assurance (.BQA) files were used to develop a cloud mask. The .BQA files were mosaicked, then values to be screened out were set to ‘0’ (all other values were set to ‘1’) using the conditional tool in raster calculator. A binary map is created and multiplied by the mosaicked bands of interest. Cloud cover comprised 4.2% of the mosaicked image, and was set to null using raster calculator. The RS indices used in the study are presented in Table 1. The calculation of each index is done by computing the arithmetic operations shown on the bands given in the table using Raster Calculator. NIR is the Near Infrared Band (wavelength = 0.851-0.879 µm), Red is the red band (wavelength = 0.636-0.673 µm), and $SWIR_1$ if the first shortwave infrared band (wavelength = 1.566-1.651 µm) on the Landsat 8 satellite. All RS indices will be ranked in ascending order, since a smaller (or a negative) value for each index implies less impact from landfills on the surrounding area.

Each normalized RS index ranges from -1 to 1. NDVI is a measure of healthy green vegetation (Mahmood et al., 2016), with a higher value indicating a healthier vegetation. Manzo et al. (2017) found that NDVI may be negatively affected by the presence of landfills, due to fugitive emissions and other pollution. Normalized Difference Built-up Index (NDBI) detects built-up areas, such as populated centers. Negative NDBI values indicate a lack of built-up areas, thus less impacts from landfilling to the human receptors are expected. Normalized Difference Moisture Index (NDMI) measures the amount of moisture in an area, with a higher value being associated with more moisture. Landfill operation may negatively affect environment, groundwater, economy, and ecology (Wang et al. 2018). Drier weather helps to reduce mobility of contaminants, and therefore better from a landfill operator point of view.

Table 1: RS indices used in this study

Remote Sensing Index	Calculation	Reference
Normalized Difference Vegetation Index	$NDVI = \frac{NIR - Red}{NIR + Red}$	Musse et al., 2018
Normalized Difference Built-up Index	$NDBI = \frac{SWIR_1 - NIR}{SWIR_1 + NIR}$	Zha et al., 2003
Normalized Difference Moisture Index	$NDMI = \frac{NIR - SWIR_1}{NIR + SWIR_1}$	Jin and Sader, 2005

2.3 Vector Data Acquisition

The vector data used in this study is summarized in Table 2. Data was gathered from a number of municipal government sources, as shown in Table 2. Populated places show the spatial distribution of population, while roads are the centerline of roads, and waste management data shows the spatial location of waste management facilities in the province. Populated places will be ranked in ascending order, because having a lower number of populated places may imply less disturbance by landfills. Roads and waste management facilities are ranked in descending order, since a higher number of either features may point to a more efficient integrated solid waste management system, given the costly collection cost typically associated with a waste management system. A higher number of roads is considered better since it may allow for improved transportation, and a higher number of waste facilities may imply a more mature waste management plan in the region.

Table 2: Vector datasets used in this study

Vector Dataset	Feature Type	Reference
Populated Places (Pop)	Point	Esri Canada, 2014
Roads	Line	Esri, 2018a
Waste Management Facilities (WMFs)	Point	Government of Nova Scotia, 2017

2.4 Workflow

The workflow used in this study is shown in Figure 2. The Zonal statistics tool is used to calculate the average value of all pixels within each zone (waste management regions) for remote sensing data, while a spatial join is used to calculate the count data for vector datasets. The results were imported to excel, and the "RANK" function was used to rank each of Nova Scotia's seven WMRs. After summing the ranking results and normalizing the data, the results were re-joined to the WM regions, and an equal interval choropleth was used to display the data. Normalization was used collapse the data into an easily comparable value.

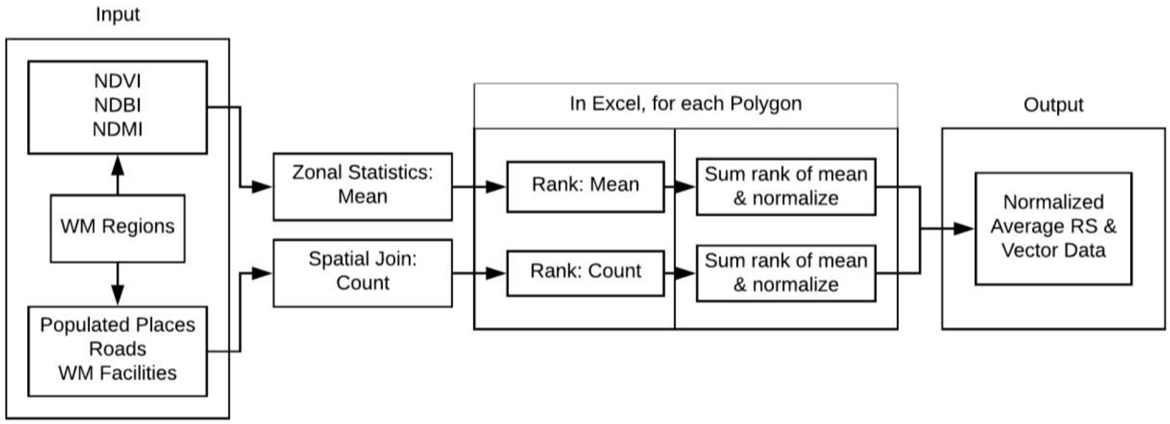

Figure 2: Workflow used in this study

3 RESULTS AND DISCUSSION

3.1 Mean Ranked WM Regions

The mean ranked sum was calculated, normalized, and is shown in Figure 3 using an equal interval choropleth of each of Nova Scotia's WMRs. The implication from this method is that area ranked better (shown in green) are less affected by landfills and other environmental parameters compared to regions ranked worst (shown in red). About 26.7% of the study area was ranked well, 38.5% was ranked moderately, and 34.8% was ranked poorly.

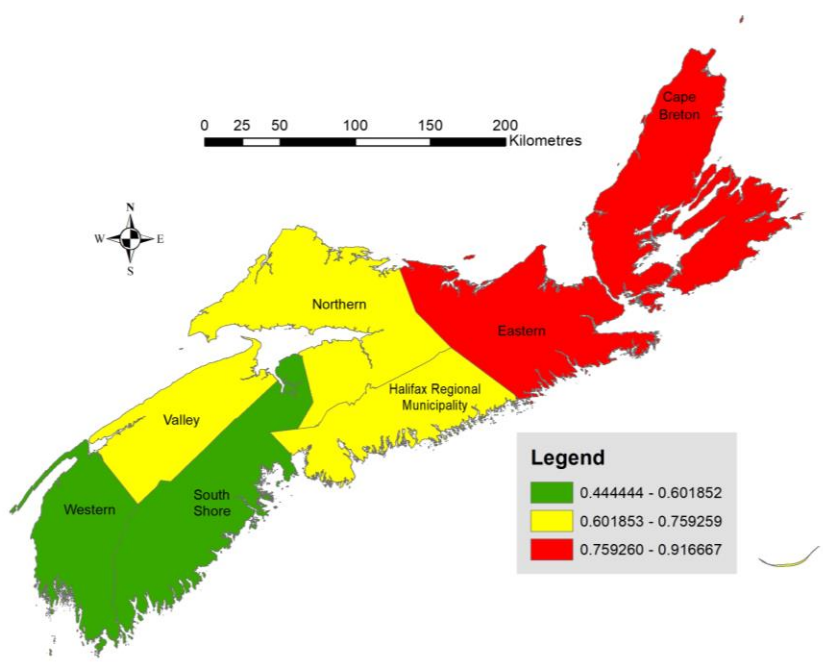

Figure 3: Mean Ranked WM Regions in Nova Scotia

Figure 4(a – c) shows the ranked contribution for each area depending on their normalized rank, shown in Figure 3. In Figure 3, areas in green are ranked better compared to regions in red. Western and South Shore ranked best (Figure 4a), Valley, Northern and Halifax Regional Municipality ranked moderately (Figure 4b), and Eastern and Cape Breton (Figure 4c) ranked the worst in term of parameters used in this study. The smaller the area of the polygon, the better the area was ranked in each respective region.

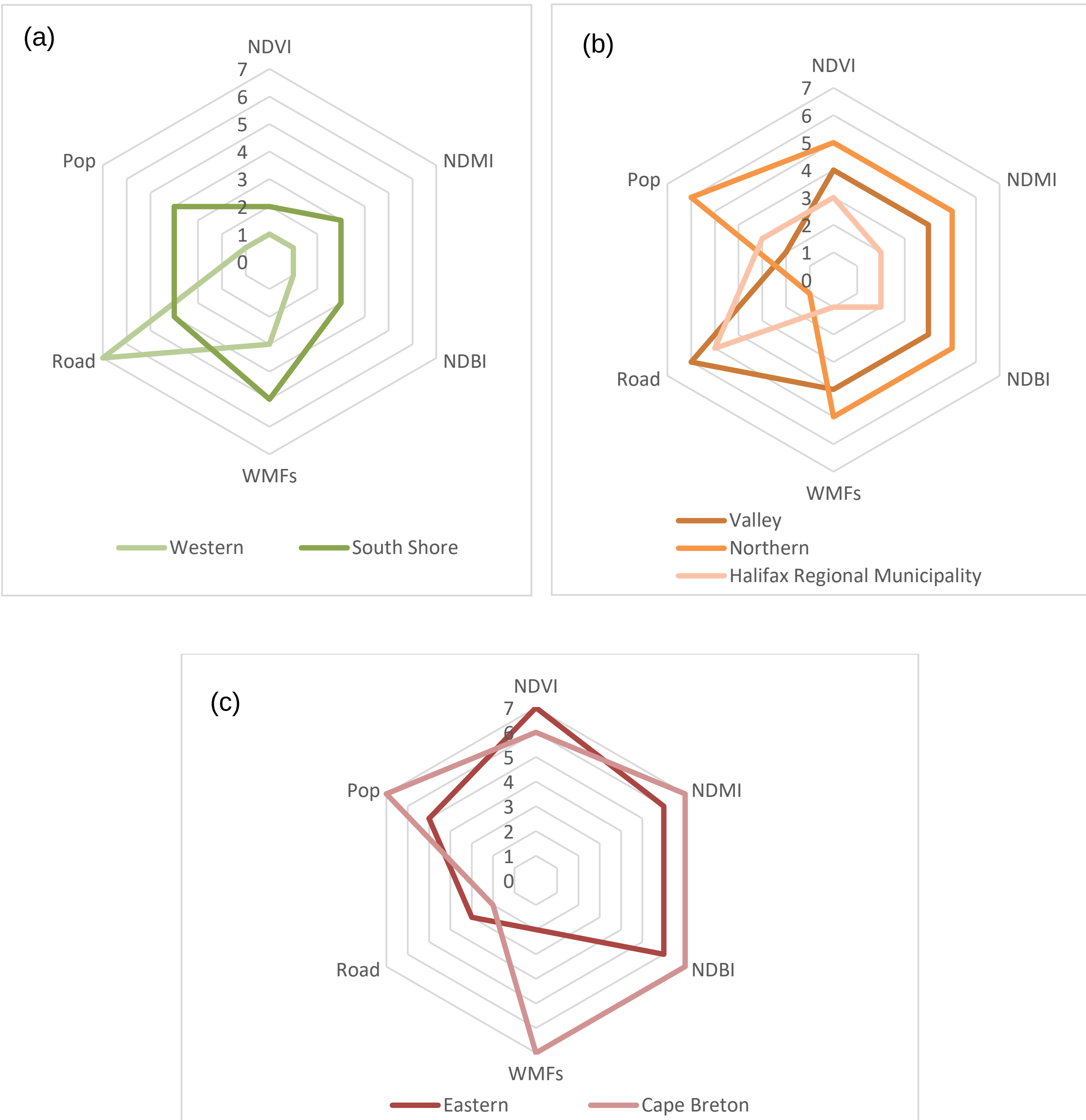

Figure 4: Contribution of each parameter to rank for regions (a) ranked highest, (b) ranked moderately, and (c) ranked lowest.

In Figure 4(a), we can see that Western WMR is ranked relatively well in all parameters except for road, in which it is ranked poorest (rank =7). This implies that there are relatively fewer roads in the area, implying that transportation of waste is relatively more expensive. South shore WMR ranked well, despite the higher contributions coming from WMFs (rank =5) and population (rank =4). Both Western and South Shore WMRs (Figure 4a) ranked relatively low in RS indices (Rank: 1-3), implying there is a relatively small amount of green vegetation, moisture, and built-up areas. The largest contributions in both Western and South Shore come from vector parameters.

Figure 4(b) shows the regions that ranked moderately (shown in Yellow in Figure 3) in the analysis. Halifax Regional Municipality (HRM) appears to be directly on the cusp of being ranked very well (based on the size of the polygon in Figures 4(a) and (b); ranking = 0.61, cut-off = 0.60, data not shown). The HRM WMR ranked worst in terms of roads, implying that transportation of waste may be relatively poor due to a lack of roads in the area. This is an interesting finding considering that HRM houses the largest city in the study area (Halifax), and the number of roads in the City is high. However, upon examination of vector data (not shown), there are very few roads in the northeast part of the WMR. HRM also had the least WMFs (rank =1), of which two were for construction and demolition disposal, two were for organics disposal, and one was for household hazardous waste, recycling, and solid waste disposal, respectively. NDBI in HRM was ranked second, indicating that there is a relative lack of built-up areas in the study area. NDBI was chosen as a measure of built-up area in this study, and the zonal statistics tool was used to calculate the mean NDBI over each WMR. The average NDBI in each of the seven WMRs was $-0.23 < NDBI < -0.29$, indicating an absence of built-up areas, which follows considering that approximately 50% of the population in Nova Scotia lives in rural areas (Statistics Canada, 2018). In this study, NDBI was found less effective in locating populated places, since the average value tool was used in Zonal Statistics. In the future, other quantification methods in Zonal Statistics should also be investigated. In a mainly rural province, NDBI may be more effective at a smaller scale. In future work, NDBI is recommended when considering a smaller discretization of area.

In the Valley WMR (Figure 4b), roads were ranked 6^{th}, while population ranked 1^{st}. This implies relatively fewer roads, with a high number of populated places. A closer look at the vector data (not shown) supports this finding, which may indicate that the area is more rural in nature (many populated places with few roads connecting them). On the other hand, in the Northern WMR, roads were ranked 1^{st} (Figure 4c), meaning that there is a large road network to support the transportation of waste. Examination of the vector dataset showed the area had a much more consistent spread of populated places compared to the Valley WMR. The contribution from RS indices was high in the Northern WMR, implying an abundance of healthy vegetation, moisture, and built-up areas. Based on examination of the true colour composite of the area, it appears that there are many small communities spread out more uniformly across the region. The area also had a high number of WMFs, including three of each Construction & Demolition and Organic waste facilities, and two of each household hazardous waste, recycling, and solid waste disposal facilities, shown in Table 3.

Table 3: Number and Type of WMFs in each WMR

WMR	Construction & Demolition	Household Hazardous	Organic Waste	Recycling	Solid Waste	Asbestos	Total
Western	3	3	2	1	0	1	10
South Shore	2	6	2	1	3	0	14
Valley	4	2	1	0	2	2	11
Northern	4	2	3	2	2	1	13
HRM	2	1	2	1	1	0	7
Eastern	4	1	2	0	0	2	11
Cape Breton	5	2	5	3	1	1	17
Total	24	16	17	8	9	7	83

Figure 4(c), shows the areas that ranked the poorest in this analysis. The Eastern region was ranked well in terms of roads (rank =3), but all RS indices ranked poorly at 6th or 7th. It appears that this area may be dominated by healthy green vegetation, but appears to also have a relatively large population (this was confirmed by examining the vector data, figure not shown). It is possible, due to the number of features in this area, that landfills or waste management facilities may have more of an impact to the environment and population compared to other regions, based on the analysis herein. Cape Breton WMR was ranked the worst in the analysis (Figure 4c), with most contributions coming from the remote sensing indices. This was verified in the GIS map, and the region appears to have a mix of both urban and rural areas. In fact, the second largest city in Nova Scotia (Cape Breton) is located in the area. The region houses the highest number of WMFs (Table 3) but is ranked best in transportation, possibly implying that there may be a good transportation network in the area for waste. The number and type of WMFs in Cape Breton is surprising, and may indicate that there are other factors at play in the area. From Table 3, there are 5 construction and demolition facilities as well as 5 organic waste facilities in the area. The high number of construction and demolition facilities may imply that there is a more vibrant construction industry in the area; while the high number of organics facilities may indicate a large agriculture, forestry, fishing, and hunting sector in the area. Richter et al. (2017) found that Nova Scotia's ban on organics entering landfills may have helped to increase the diversion rate in the province. As a result, the high number of OCW facilities in the Cape Breton WMF indicates that more organics processing occurs in the area, possible due to the type of industries in the area (Richter et al., 2017). However, these claims could not be verified due to the reporting structure of sectors in Nova Scotia.

Overall, it is interesting to note that RS indices appear to drive poorer rankings. For example, note that in Figure 4(c), the main contribution to the poor ranking in Cape Breton is from RS indices (NDVI = NDMI = NDBI = 7). On the other hand, in Figure 4(a), Western has a ranking of 1 for NDVI, NDMI, and NDBI. The opposite is true of vector data in Figure 4(c) and Figure 4(a), respectively. This demonstrates the usefulness and ability of RS and vector data to show distinctively different aspects of the study area.

NDMI and NDVI are very similar in each region in this study. In Figure 4(a-c), NDMI and NDVI are either ranked exactly the same, or are within one rank (on either side) of each other. In future analyses, other RS indices should be investigated. As mentioned previously, because of the highly rural nature of the province, RS indices may be less effective at such a large scale, and perhaps a finer discretization of the province would be more appropriate for such an analysis.

In general, Nova Scotia performs relatively well, with the 65.2% of the area ranking well or moderately in terms of waste management based on the method presented (Figure 3). RS indices generally seemed to contribute more to a poorer ranking, meaning that areas that ranked poorest likely had either a lot of healthy green vegetation (and moisture, as a result of high NDVI) or had highly populated areas. Cape Breton for example, was characterized by both a high NDBI and high NDVI. Interestingly, Halifax (in the Halifax Regional Municipality) ranked relatively better, which may be due to the split of rural and urban areas within the region. The disparity between the number of WMFs in Halifax and Cape Breton is worth more investigation, as it may be related to industries in each area.

Without a doubt, Nova Scotia represents one of the most organized integrated waste management systems in Canada, if not the world. This analysis aims to rank each region, in order to see what features make a region relatively better or worse. However, the authors understand that the features within each region may necessitate or drive other parameters used in the study. For example, a high NDVI may necessitate a high number of organics processing facilities due to the industries and other environmental factors in the area.

The proposed method is extremely sensitive to the parameters chosen. The method used in this study is very flexible and can be easily adjusted to look at different parameters. Furthermore, the method does not make use of any type of expert opinion or weighting, making it a useful screening tool.

4 CONCLUSIONS

In this study, GIS is used to combine vector and RS data in order to rank waste management regions in Nova Scotia. Populated centers, roads, and landfill facilities represent the vector data, while NDVI (vegetation), NDMI (moisture), and NDBI (built-up) indices represent the remote sensing data in this study. About 26.7% of the study area was ranked well, 38.5% was ranked moderately, and 34.8% was ranked poorly.

Results show that Western and South Shore WMRs ranked the best; Valley, Northern, and Halifax Regional Municipality ranked moderately; while Eastern and Cape Breton ranked poorly. The regions that ranked poorly were most affected by landfills, while the regions ranked best were perhaps less affected by landfills. Halifax Regional Municipality, which ranked moderately, has the fewer number of WMFs, but ranked poorest in road network, which is surprising considering the fact that it houses the largest city in the study area (Halifax). In this study, NDBI was found to be ineffective in measuring built-up index is the regions, since Nova Scotia is mainly rural. The "average" tool in Zonal Statistics did not effectively measure NDBI in this region, which is characterized by rural areas. Cape Breton WMR ranked worst in the analysis. The area appears to be dominated relatively equally by urban and rural areas. The area ranked worst in number of WMFs, but ranked best in transportation, which may imply a very efficient waste transportation network. The high number of C&D and OCW facilities (a total of 10) in the area may imply a presence of construction and agriculture, forestry, fishing, and hunting industries in the area, though this claim could not be verified. Generally, RS indices appeared to be responsible for poor rankings, demonstrating that vector and RS data may complement each other well. The analysis is sensitive to the parameters chosen and how they are quantified.

Areas of future work may include the use of RS indices that better represent the area, or finer discretization of the study area which may lead to more interesting findings. It appears that the 'average' tool in Zonal Statistics was not effective for quantifying remote sensing indices in Nova Scotia, indicating that other quantification methods should be investigated. This method is advantageous because it does not rely on expert opinion or weighting, making it a useful screening tool.

4.1 Acknowledgements

The research reported in this paper was supported by a grant from the Natural Sciences and Engineering Research Council of Canada (RGPIN-385815), using computing equipment funded by FEROF at University of Regina. The authors are grateful for their support. The views expressed herein are those of the writers and not necessarily those of our research and funding partners.

4.2 References

Alexakis, D.D., and Sarris, A. (2014). Integrated GIS and remote sensing analysis for landfill sitting in Western Crete, Greece. *Environmental Earth Sciences,* **72**, 467-482. DOI: 10.1017/s12665-013-2966-y

Esri Canada. (2014). Canada Populated Places. Accessed from https://www.arcgis.com/home/item.html?id=9858f881b31c4187bd95c74ab46be44b on July 19th, 2018.

Esri. (2018a). World Street Map. Accessed from https://www.arcgis.com/home/item.html?id=3b93337983e9436f8db950e38a8629af on July 19th, 2018

Faisal, K.S. (2011). Environmental monitoring of landfill sites using multi-temporal remote sensing images. *Master's Thesis*. King Abdul Aziz University, Jeddah, Saudi Arabia.

Government of Nova Scotia (1995). Solid Waste-Resource Management Strategy. Accessed from https://novascotia.ca/nse/waste/swrmstrategy.asp#section02 on November 3rd, 2018

Government of Nova Scotia. (1995). Solid Waste Resource Management Strategy. Accessed from https://novascotia.ca/nse/waste/swrmstrategy.asp on October 30th, 2018.

Government of Nova Scotia. (2017). Environment – Facilities. Accessed from https://novascotia.ca/nse/waste/facilities.asp on January 23rd, 2019.

Jin, S., and Sader, S.A. (2005). Comparison of time series tasseled cap wetness and the normalized difference moisture index in detecting forest disturbances. *Remote Sensing of Environment*, **94**(3), 364-372. DOI: 10.1016/j.rse.2004.10.012

Khan, M.M., Vaezi, M., Kumar, A. (2018). Optimal siting of solid waste-to-value-added facilities through a GIS-based assessment. *Science of the Total Environment*, **610-611**, 1065-1075.

Khodaparast, M., Rajadi, A.M., Edalat, A. (2018). Municipal solid waste landfill siting by using GIS and analysis hierarchy process (AHP): a case study in Qom City, Iran. *Environmental Earth Science,* **77**:52.

Madi, S., and Srour, I. (2019) Managing emergency construction and demolition waste in Syris using GIS. *Recycling, Conservation, and Resources,* **141**, 163-175. DOI: 10.1016/j.resconrec.2018.10.018

Mahmood, K., Batool, A., Faiza, F., Chaudhry, M.N., Ul-Haq, Z., Rana, A.D., and Tariq, S. (2017). Bio-thermal effects of open dumps on surroundings detected by remote sensing – Influence of geographical conditions. *Ecological Indicators*, **82**, 131-142. DOI: 10.1016/j.ecolind.2017.06.042

Mahmood, K., Batool, S.A., and Chaudhry, M.N. (2016). Studying bio-thermal effects at and around MSW dumps using Satellite Remote Sensing and GIS. *Waste Management,* **55**, 118-128. DOI: 10.1016/j.wasman.2016.04.020

Manzo, C., Mei, A., Fontinovo, G., Allegrini, A., and Bassani, C. (2016). Integrated remote sensing for multi-temporal analysis of anthropic activities in the south-east of Mt. Vesuvius National Park. *Journal of African Earth Sciences*, **122**, 63-78.

Manzo, C., Mei, A., Zampetti, E., Bassani, C., Paciucci, L., and Manetti, P. (2017). Top-down approach from satellite to terrestrial rover application for environmental monitoring of landfills. *Science of the Total Environment*, **548-585**, 1333-1348. DOI: 10.1016/j.scitoenv.2017.01.033.

Musse, M.A., Barona, D.A., and Rodriquez, L.M.S. (2018). Urban environmental quality assessment using remote sensing and census data. *International Journal of Applied Earth Observation and Geoinformation*, **71**, 95-108. DOI: 10.1016/j.jag.2018.05.010.

Richter, A., Bruce, N., Ng, K.T.W., Chowdhury, A., and Vu, H.L. (2017). Comparison between Canadian and Nova Scotian waste management and diversion models – A Canadian case study. Sustainable Cities and Society, **30**, 139-149. DOI: 10.1016/j.ses.2017.01.013

Richter, A., Ng, K.T.W., and Pan, C. (2018). Effects of percent operating expenditure on Canadian non-hazardous waste diversion. *Sustainable Cities and Society*, **38**, 420-428.

Statistics Canada (2018). Canada at a Glance, 2018 – Population. Accessed from https://www150.statcan.gc.ca/n1/pub/12-581-x/2018000/pop-eng.htm on February 4th, 2019.

Statistics Canada (2019). Materials diverted, by source – Table 38-10-0033-01. Accessed from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810003301 on February 10th, 2019.

Wang, Y., Li, J., An, D., Xi, B., Tang, J., Wang, Y., and Yang, Y. (2018). Site selection for municipal solid waste landfill considering environmental health risks. *Resources, Conservation & Recycling*, **138**, 40-46. DOI: 10.1016/j.resconrec.2018.07.008

Zha, Y., Gao, J., and Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing,* **24**(3), 583-594. DOI: 10.1080/01431160210144570