

TRAIL ROAD LANDFILL SITE MONITORING USING MULTI-TEMPORAL LANDSAT SATELLITE DATA

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ABSTRACT:

The disposal of the solid wastes in landfill sites should be properly monitored by analyzing samples from soil, water, and landfill gases within the landfill sites. Nevertheless, ground monitoring scheme requires intensive efforts and cost, and sometime it is difficult to be achieved in large geographic extent. Remote sensing technology has been introduced for waste disposal management and monitoring effects of the landfill sites on the environment. This paper presents a case study to evaluate the use of multi-temporal remote sensing data to monitor and assess the effects of landfill sites on the environment. The study area covers the Nepean and Trail Road landfill sites (the main municipal waste disposal site for the city of Ottawa). The Nepean landfill site was opened in 1960s, accepted waste until 1980s and finally capped in 1993. With the increasing amount of waste disposal, the Trail Road landfill was then constructed and was in operation in early 1980. The Trail Road landfill, which is still in operation, is comprised of four phases developed sequentially. Thirteen bi-yearly multi-temporal Landsat satellite images acquired during July and August from the year 1985 to 2009 are used to calculate the Soil Adjusted Vegetation Index (SAVI) and the Land Surface Temperature (LST). The differences of the LST between the landfill sites (due to the release of the landfill gases within the landfill site) and the surrounding areas are analyzed. Furthermore, the LST of the landfill sites are monitored to assess the decomposition activities of the waste disposal. Preliminary data analysis reveals that the LST of the landfill site is higher than the immediate surrounding areas and the air temperature during the decomposition process by up to 9 °C and 14 °C, respectively. In the Trail Road landfill site, the LST of the active phases of the landfill site is higher than the closed phases of the landfill site by around 3 to 5 °C. The SAVI is used to investigate the healthiness of the vegetation of the immediate surroundings areas. It was found that the closer the location of the vegetation to the landfill site, the comparatively lower SAVI values are found. The lower SAVI of the surrounding vegetation can be explained due to the existence of the leachate produced from the decomposition process.

1. INTRODUCTION

Solid waste management is a problem faced by many countries. The majority of the solid wastes are still buried in landfill sites. The disposal of the solid wastes in landfill sites without proper pre-treatment and monitoring may cause environmental, financial, and public health impact. Therefore, continuous monitoring of the landfill sites should be carried out. Common monitoring schemes require acquiring chemical compositions of groundwater and surface water from monitoring wells and surrounding water ponds/streams. The samples acquired are then analyzed in the laboratory for a series of common leachate indicator parameters. Although such ground monitoring scheme is useful and precise, it requires intensive effort and is difficult to examine and monitor the impact of the landfill sites in a large geographic extent. In addition, evaluating the impact of the landfill site on the environment may not be possible for some long existing landfill sites where onsite data may not be available. In this regards, remote sensing technology has been introduced for waste disposal management and monitoring.

Lukashev et al. (2001) reviewed the use of expert system and Geographic Information System (GIS) to design and monitor landfills and to devise decision support systems (DDS) to simulate and solve complex environmental problems during the landfill design process. For waste disposal site planning, multiple factors should be considered to design and determine optimal location which fulfil the requirements of the local

Government's law and minimize the environmental, financial and public health impact. As this decision making process deals with large amount of geographic information such as existing land use, road network, geology, water supply sources, etc., GIS can assist the evaluation process by overlay all these GIS data layers for optimum site searching (Kontos et al., 2005; Roozbah, et al., 2005; Gómez-Delgado and Tarantola, 2006; Higgs, 2006; Sumathi et al., 2008).

The optimum transportation route of waste is another important factor during the design process. GIS-based transportation models for optimal route searching of transporting solid waste to landfill sites are also introduced (Ghose et al., 2006; Paudel et al., 2009). By using GIS network analysis, minimum cost/distance efficient collection paths can be determined for efficient management of daily operations. Tavares et al. (2009) further enhance the idea of optimal route searching using 3D GIS model for minimum fuel consumption.

GIS spatial analysis function is also used to assess and monitor the environmental impact of landfill sites on the surroundings. Spokas et al. (2003) introduced Kriging interpolation technique to determine the landfill methane emission for the whole site in order to assess the impact on the environment. Another stream of research utilized remote sensing technique to map and monitor existing or illegal landfill sites for prosecution or environmental study.

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Aerial photo interpretation technique using black and white aerial photos is an early approach to identify the hazardous of waste sites based on the shape, texture of surrounding features, and spectral reflectance of the landfill sites (Bagheri and Hordon, 1988). Pope et al. (1996) proposed digital analysis approach to derive characterization information on the disposal sites using co-registered aerial images. All these previous works mainly reply on the visual inspection on the image without statistical analysis. Ottavianelli (2007) investigated the possibility of distinguishing landfill sites from other land features using Synthetic Aperture Radar (SAR) and correlated the SAR data with the onsite conditions and operational procedures. The experiments demonstrated the usefulness of spatial characteristics of SAR backscatter and complex degree of coherence for landfill site identification. Silverstri and Omri (2008) used image classification techniques and GIS information to identify uncontrolled landfill sites. Biotto et al. (2009) further adopted GIS statistical analysis to produce probability map to narrow down the set of possibly contaminated sites on Silverstri and Omri's dataset.

To assess the landfill gas migration, surface temperature derived from remote sensing technique can be used. Kwarteng and Al-Enezi (2004) adopted multi-temporal Landsat data to monitor a large landfill site in Kuwait with the land surface temperature (LST). 1 to 4 °C temperature difference was found from the landfill site to the immediate surroundings. Similar study was conducted (Yang et al., 2008) to assess the impact of potential threats of landfill sites in Jiangsu province of China with the surface temperature and normalized difference vegetation index (NDVI) derived from a single Landsat ETM+ image. With the aid of GIS spatial analysis, evaluation the compliance of landfill site location and leachate quality with the relevant national regulations was conducted. In addition, four potential location were deemed as inappropriate for establishment of landfill sites.

In this study, bi-yearly multi-temporal Landsat satellite images from the year 1985 to the year 2009 are used to evaluate the use of the remote sensing techniques in landfill site monitoring with a case study in the city of Ottawa. The study is based on the analyses of the calculated SAVI and the LST for the landfill sites and the surrounding areas.

2. BACKGROUND OF THE LANDFILL SITES

The study is conducted on the Trail Road landfill site of the city of Ottawa, Ontario, Canada (45° 14' N, 75°45' W) shown in Figure 1. It is located within the region of Ottawa Carleton, Canada, with a population of 750,000. The landfill site is approximately 500 acres which is surrounded by light industry and farmlands, and highway 416. The Trail Road landfill is a primary disposal facility for municipal solid waste of the city of Ottawa. It is a municipal sanitary landfill site, which accepts nonhazardous waste including residential garbage, construction, commercial, institutional, and light industrial waste (Dillon Consulting Ltd., 2008).

The establishment of the Trail Road landfill was mainly due to the full operation of the adjacent Nepean landfill (operated since early 1960s and accepted waste until the early 1980s). With the increasing amount of waste disposal, the Trail Road landfill were established based on the new property area that was acquired to the Nepean landfill site in March 1975 on the North side of the Trail Road. In December 1978, the Trail Road

landfill was constructed and waste disposal operations began starting from May 1980. Trail Road landfill comprises four phases which were developed sequentially beginning at phase 1 (farthest to the East) and moving Westwards to phase 4 (Dillon Consulting Ltd., 2008).

The Nepean and Trail Road landfill sites are operated and managed under the environmental monitoring program which is approved by the Ontario Ministry of Environment. Samples of ground water and surface water are acquired in the monitoring wells within the sites, and the surrounding stream and pond stations, respectively. The purpose is to measure and record the chemical composition of the water samples in order to investigate landfill leachate effects to the surrounding environment. Landfill gas monitoring wells are also existed on the landfill sites to measure the concentration of the methane in the samples. All these ground measurements form a comprehensive environmental monitoring program and are required to report to the Government of the City of Ottawa annually. In this study, preliminary analysis of satellite-data is reported for the landfill sites and the immediate surrounding areas. The main objective is to investigate the possible use of remote sensing techniques in landfill site monitoring. In this study, ground measurements are used to further explain the findings from the remote sensing data.

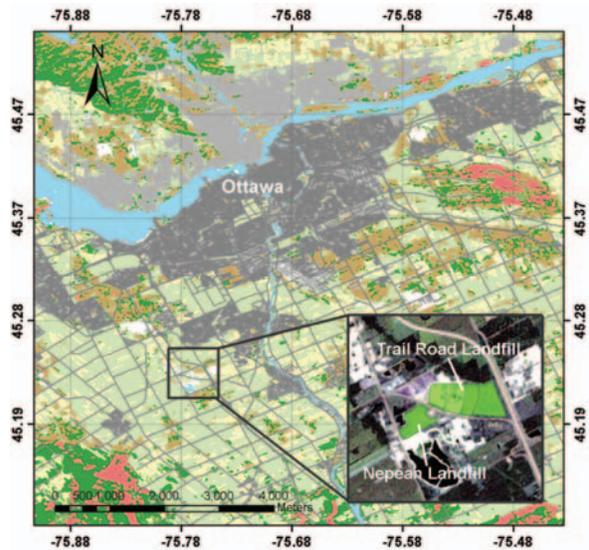


Figure 1. Study area of the Nepean and the Trail Road landfill sites

3. DATASETS AND METHODS

The study area is covered by Landsat satellite images taken from path 15 and 16 and row 28 and 29. Over 100 Landsat TM and ETM+ images are downloaded from the USGS Earth Explorer for years from 1984 to 2009. The spatial resolution of the Landsat TM and ETM+ data are 30 m for the multi spectral bands and 60 m for the thermal bands. All the images are imported into PCI Geomatics V10.1, clipped and projected into the UTM 17N coordinate system. Each Landsat image is separated into two files due to the different spatial resolution. Bands 1 (blue), 2 (green), 3 (red), 4 (near infrared red), 5 (mid infrared red) and 7 (mid infrared red) are combined into one PCI file and the thermal bands (Band 6 for Landsat TM are combined in another PCI file. In this study, thirteen years of

Landsat images are used for the analysis taken during the summer period of July and August from 1985 to 2009 (bi-yearly). Images captured almost at the same period of time are used to avoid the significant atmospheric variation due to the seasonal changes. Table 1 shows the list of multi-temporal Landsat data used for the environmental monitoring of the Nepean and Trial Road landfill sites.

Acquisition Date	Landsat Sensors	Path / Row
5 th August 1985	TM	16 / 29
11 th August 1987	TM	16 / 29
31 st July 1989	TM	16 / 29
22 nd August 1991	TM	16 / 29
10 th July 1993	TM	16 / 29
10 th August 1995	TM	15 / 29
30 th July 1997	TM	15 / 29
28 th August 1999	TM	16 / 29
1 st August 2001	TM	16 / 29
15 th July 2003	TM	15 / 29
20 th July 2005	TM	15 / 29
26 th July 2007	TM	15 / 29
15 th July 2009	TM	15 / 29

Table 1. Multi-temporal Landsat images used in this study

Previous landfill studies using Landsat satellite images might not consider atmospheric correction on the multi-date Landsat Images (Kwarteng and Al-Enezi, 2004; Yang et al., 2008). However, many remote sensing studies have addressed the importance of the atmospheric correction for the calculation of the vegetation indices and the land surface temperature (Ou et al., 2002; Jensen, 2005; Hadjimitsis et al., 2010). There are two different ways of atmospheric correction, absolute correction and relative correction. Although relative correction approach is easier to be implemented, absolute correction preserves better results than relative approach if sensor parameters and weather condition can be acquired (Paolini et al., 2006).

In this study, the ATCOR2 absolute atmospheric correction model (Ritcher, 1996) built in PCI Geomatics is used to correct the thirteen multi-temporal Landsat images. The sensor information (sensor type, acquisition date, and pixel size), the atmospheric condition (reference to the weather information from the Ottawa weather office), the calibration information for the Landsat TM images (Chander et al., 2007) and the correction parameters (solar zenith and azimuth, visibility, and adjacency) are used to atmospherically correct the Landsat images. The output of the ATCOR2 model includes the corrected original Landsat image and an option to calculate the LST and the SAVI from the original images. Figure 2 shows the experimental workflow adopted in this study. Preliminary analysis is conducted to assess the impact of the landfill sites on the surrounding environment by comparing the information of the LST and SAVI extracted from the Landsat images. Further evolution to the analysis are achieved by integrating the ground monitoring data, such as the ground/surface water levels, the landfill gas concentration, and the soil sampling, with the image satellite data.

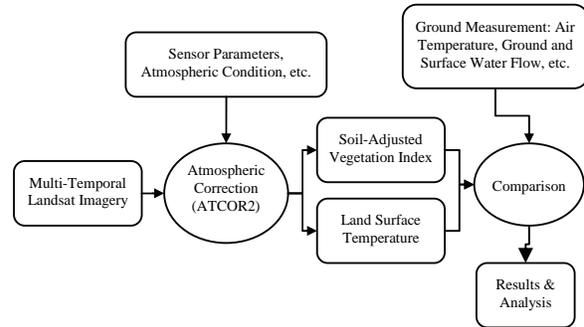


Figure 2. Experimental workflow

4. RESULTS AND ANALYSIS

Figure 3 shows the average LST for different years of the Trial Road and the Nepean landfill sites. Generally, it is found that the Trail Road and the Nepean landfill sites always have higher LST temperature comparing to both the surrounding vegetation and the air temperature by about 9°C and 14°C, respectively. The air temperatures are observed by the hourly weather record at the Ottawa Macdonald-Cartier International Airport which is around 10 km from the landfill sites. The higher the LST of the landfill sites can be explained due to the decomposition process of the wastes and the release of the landfill gases from the landfill sites. The calculation of the LST of the landfill sites for the period from 1985 to 1993 shows decline in the LST of the landfill sites. This observation matches the expectation due to the transition period between the closer of the Nepean landfill site and the opening of the Trail Road landfill site. These findings have been confirmed by the ground observations of the monitoring stations distributed on the site.

The Nepean landfill site is constantly (except for the year 2009) in few degree Celsius lower LST comparing to the Trail Road landfill site as it is closed completely in the early 1980s and is finally covered in 1993. The year 2009 shows high LST in the Trail Road landfill site comparing to Nepean landfill site because of the recent approved expansion of the Trail Road landfill site to increase the site capacity. The landfill expansion led to further construction activities which can be found on the recent images. Details on LST analysis are being conducted to investigate the differences in the LST amongst the four phases of the Trail Road landfill site.

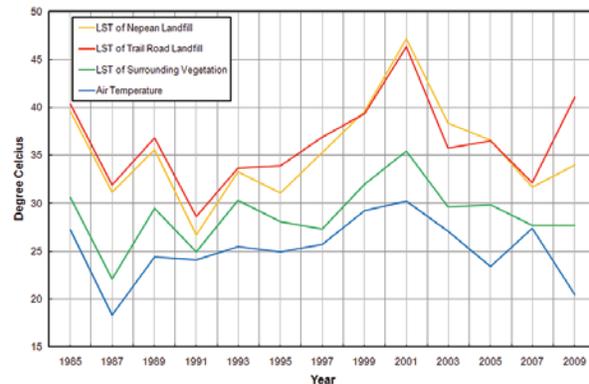


Figure 3. Land surface temperature and air temperature of the study area

Figure 4 shows the land surface temperature of the four different phases of the Trail Road landfill site. In year 1985, it is found that the LST of phase 1 is higher than the LST of phases 2, 3 and 4. The higher temperature of phase 1 comparing to other phases is mainly because of the higher disposal activity in phase 1 with respect to the activities in other phases. However, the LST of phase 1 became significantly lower than the other 3 phases starting from the year 1987 by 3 to 5 °C. This observation is linked to the closer and capping of phase 1 in the year 1988. As phase 2 of the Trail Road landfill was closed and capped in year 1991, the LST of phases 1 and 2 are constantly lower than the LST of phases 3 and 4 by around 5 °C except recent years. This is because the Trail Road landfill is recently approved for vertical expansion and construction activities are found in the recent year images.

The lower surface temperature of phase 1 and 2 after the year 1991 can be explained due to the vegetation cover of the closed phases which cool down the temperature of the landfill site. In addition, the much differences between the LST of phases 1 and 2 and phases 3 and 4 starting from the year 2007 can also be explained due to the recently installed renewable electric generating facility at the Trail Road landfill site started in 2007 for green energy. This facility is useful to transform the landfill gases into green energy and may minimize the LST of the landfill sites.

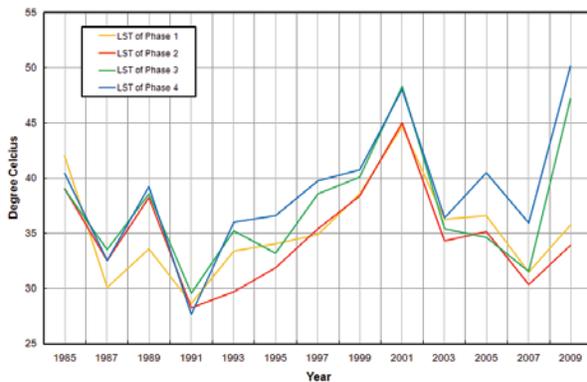


Figure 4. Land surface temperature of the four phases in the Trail Road landfill

Apart from studying the LST of the landfill sites, the impact of the landfill sites on the surrounding areas are also investigated using the SAVI. Low SAVI value (close to 0) refers to non-/unhealthy vegetation area where high SAVI value (close to 1) indicates dense healthy vegetation. Ten buffer zones are created around the landfill sites in 100 m width in the four main directions (East, West, North and South) (Figure 5). The SAVI of the immediate surrounding vegetation is calculated for the buffer zones. As the buffer zones covers some of the non-vegetation areas (e.g. houses, road), these areas are excluded from the calculation of SAVI statistics of the surrounding vegetation.

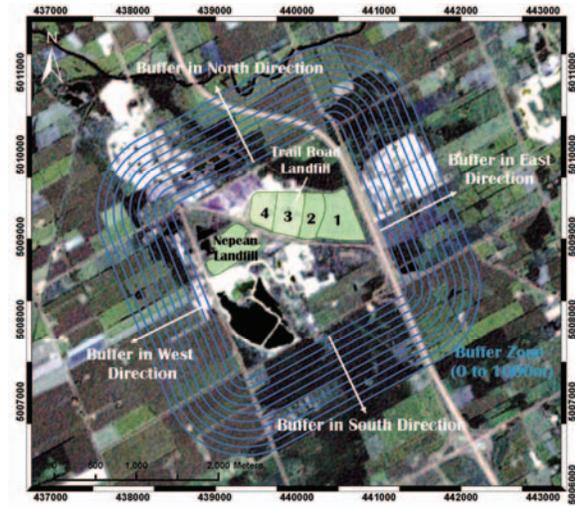


Figure 5. Buffer zone for the surrounding vegetation

The SAVI values calculated in the four directions reveal that reductions of 0.05 is found in the first 200 m of the buffer zones where the East direction is not counted due to the existence of the highway 416. The SAVI buffer zones after the first 200m are slightly higher in the West direction (~0.35) comparing to the buffer zones of the East (~0.25), South (~0.3) and North (~0.3) directions. Closer look at the ground elevations of the surrounding areas of the landfill sites and the water table levels shows that the East, North and South directions are lower than the West direction. Figure 6 shows an example of SAVI of the study area in year 2009. In addition, the ground water flow is heading to the North direction with reference to the ground measurement data. Records from the monitoring ground stations shows some levels of leachate influences in the underground water are observed in the North of the Trail Road landfill in 2007 (Dillon Consulting Limited, 2008). Observations from the SAVI of the surrounding areas to the landfill site confirmed the ground observations. It is also found that the closer the location to the landfill sites the more soil and water contamination and the more effect of the vegetation. This finding is valid considering the earth level in the areas surrounding the landfill site.

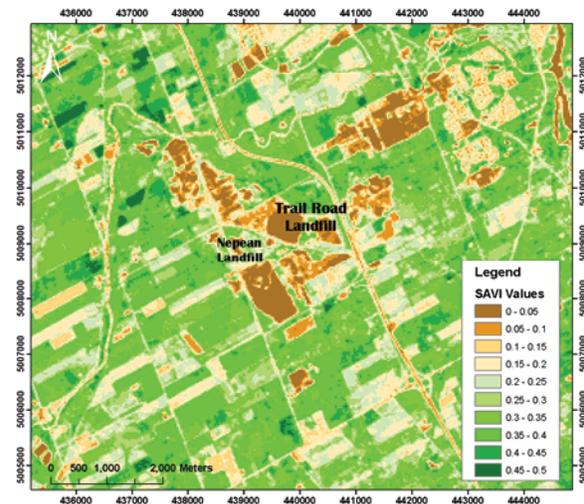


Figure 6. An example of SAVI in year 2009

5. CONCLUSIONS

This study is conducted to use multi-temporal Landsat imagery for assessing the impact of landfill sites on the environment. The case study covers the Nepean and Trail Road landfill sites at the city of Ottawa, Canada. Thirteen Landsat TM satellite images taken from the year 1985 to 2009 are downloaded from the free archives of the USGS EarthExplorer. The multi-temporal Landsat images are radiometrically corrected using the ATCOR2 atmospheric correction model using PCI Geomatics. Land Surface Temperature (LST) and the Soil-Adjusted Vegetation Index (SAVI) are calculated to monitor the activity of the decomposition process and the effect of the landfill sites on the surrounding vegetations.

The results show that the LST of the landfill sites are always higher than the LST of the surrounding areas by about 9 °C. It is also found that the landfill sites have LST of about 14 °C higher than the actual air temperature acquired from the Ottawa Macdonald-Cartier International Airport. Closed phases of the Trail Road landfill site has lower surface temperature than the active phases by 3 to 5 °C. This is explained due to the decomposition activity within the landfill sites leading to the emission of warm gases from the landfill site.

The study also investigates of the healthiness of the vegetation surrounding the landfill sites by acquiring the SAVI from the landfill sites and the immediate surrounding areas. The closer the location of the vegetation to the landfill site, the lower SAVI values are found. In addition, areas with lower terrain elevations are more affected by the landfill site. The study demonstrates the usefulness of the use of multi-temporal free archive Landsat images provided by the USGS as an additional data source to monitor activities on large landfill sites. Further analysis will be conducted to integrate the ground-based measurements (e.g. groundwater and surface contamination, landfill gases, etc.) and the observations from the satellite images. Consecutive years of Landsat TM images will also be processed in order to conduct a comprehensive analysis for the study area.

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