Waste Management 55 (2016) 118–128

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Studying bio-thermal effects at and around MSW dumps using Satellite Remote Sensing and GIS

Khalid Mahmood [a,*], Syeda Adila Batool [a], Muhammad Nawaz Chaudhry [b]

[a] Remote Sensing and GIS Group, Department of Space Science, University of the Punjab, 54590 Lahore, Pakistan
[b] College of Earth and Environmental Sciences, University of the Punjab, 54590 Lahore, Pakistan

ARTICLE INFO

Article history:
Received 28 January 2016
Revised 4 April 2016
Accepted 18 April 2016
Available online 26 April 2016

Keywords:
Land surface temperature
Vegetation indices
MSW dumping
Bio-indicators
Satellite Remote Sensing
Spatial analysis

ABSTRACT

Estimating negative impacts of MSW dumps on its surrounding environment is the key requirement for any remedial measures. This study has been undertaken to map bio-thermal effects of MSW dumping at and around dumping facilities (non-engineered) using satellite imagery for Faisalabad, Pakistan. Thirty images of Landsat 8 have been selected after validation for the accuracy of their observational details from April 2013 to October 2015. Land Surface Temperature (LST), NDVI, SAVI and MSAVI have been derived from these images through Digital Image Processing (DIP) and have been subjected to spatio-temporal analysis in GIS environment. MSW dump has been found with average temperature elevation of 4.3 K and 2.78 K from nearby agriculture land and urban settlement respectively. Vegetation health has been used as the bio-indicator of MSW effects and is implemented through NDVI, SAVI, MSAVI. Spatial analyses have been used to mark boundary of bio-thermally affected zone around dumped MSW and measure 700 m. Seasonal fluctuations of elevated temperatures and boundary of the bio-thermally affected zones have also been discussed. Based on the direct relation found between vegetation vigor and the level of deterioration within the bio-thermally affected region, use of crops with heavy vigor is recommended to study MSW hazard influence using bio-indicators of vegetation health.

1. Introduction

Although dumping of Municipal Solid Waste (MSW) is at bottom in the hierarchy of waste management solutions, yet it is the most used one. MSW dumps release environmental degrading emissions as a result of various biological and chemical transformations, in the form of gaseous and liquid compounds, over hundreds of years (Wang et al., 2012; Hard et al., 2013). These transformations are generally divided into hydrolysis, acidogenesis, acetogenesis and methanogenisis (Vaverkova and Adamcova, 2015).

In general MSW dumping facilities are well established and engineered with well-designed monitoring systems i.e. groundwater monitoring, leachate collection, soil sampling and analysis etc. (Yan et al., 2014). Under these systems, to assess level of biodegradation stability, samples are regularly collected and analyzed for organic content, chemical and biological properties (Cobo et al., 2008). These assessments provide an understanding of the potential risks associated with MSW emissions and lead towards its sustainable management. Worst scenario exists in the developing world where, due to limited resources, open dumping of MSW in very common (Ali et al., 2014; Mahmood et al., 2015).

The open dumping (non-engineered landfills) of MSW poses grave consequences to both groundwater and nearby soils, that results in poor vegetation health (Bellezoni et al., 2014; Ali et al., 2014). The waste may contain different metals like Cd, Cu, Ni, Pb, and Zn that can affect plants by altering chemistry of soil (Shaylor et al., 2009). Fertility of soil may be damaged as a result of physiological disorders caused by metals absorbed through root system of plants, which retards their growth and vigor (Ali et al., 2014). Literature shows evidence of extreme hazards caused by open dumping of MSW to plant life and health leading towards irreversible erosion trends (Phil-Eze, 2010). Pollutants from MSW dumping start causing invisible injuries to plants by hindering their normal metabolism owing to which visible damage appears after some time (Ali et al., 2014). These consequences upset the naturally balanced ecosystem.

One of the controlling factors of the ongoing decomposition of MSW is temperature at the dumping facility. It determines behavior of resulting leachate and gases i.e. elevated temperature reduces emission of methane by increasing its oxidation (Hanson et al., 2010; Bo-Feng et al., 2014). An extensive literature about

* Corresponding author.
E-mail addresses: khalid.m270@yahoo.com (K. Mahmood), aadila_batool@yahoo.com (S.A. Batool), muhammadnawazchaudhry@yahoo.com (M.N. Chaudhry).

http://dx.doi.org/10.1016/j.wasman.2016.04.020
0956-053X/

production and toxic effects of leachate and gas can be found but very limited information is available on thermal behavior of dumped MSW (Hanson et al., 2010; Vaverkova and Adamcova, 2015). Dumped MSW is a three-phase complex system, running several biological, physical and chemical processes in parallel. All the three types of processes are responsible for the generation of heat (Faitli et al., 2015). Heat generation values for anaerobic and aerobic decomposition as measured by Hanson et al. (2013) are 0.38 and 11.3 W/m^3 respectively. Yoshida and Rowe, 2003 have also reported a similar comparison of decomposition types. There are many other controlling factors of heat generation as well i.e. age of the waste (Hanson et al., 2008; Liu, 2007), size and height of the waste heap (Vaverkova and Adamcova, 2015). Most of the studies had simply used a constant elevated value of the dumping facilities to model performance of their environment protection level without incorporating seasonal effect that may generate a varying elevation value by controlling rates of decomposition (Doll, 1997; Southen and Rowe, 2005). Analytical solutions to study seasonal cycles of elevated temperature are also available in the literature (Carslaw and Jaeger, 1959; ORNL, 1981; Yesiller et al., 2005; Hanson et al., 2010). Most of the Land Surface Temperature (LST) data collected and studied by researchers is taken by limited ground measurements over MSW dumping sites (Hanson et al., 2010). In this regard a long list of in situ temperature measuring devices is presented in literature including thermocouples, piezometers, thermistors and a simple mercury thermometer (Yesiller et al., 2005; Koerner and Koerner, 2006; Han et al., 2007; Vaverkova and Adamcova, 2015).

Implementation of proper monitoring systems requires up to date equipment and laboratories which demand budget and expert man power. Considering these limitations of cost and effort, researchers are attempting to find other feasible solutions for monitoring generation of thermal energy from dumped MSW. Use of remotely sensed satellite data has emerged as a supplementary and cost effective substitute of MSW dump monitoring even at large scale (Jones and Elgy, 1994; Gao and Liu, 2010; Yan et al., 2014). Satellites have onboard thermal sensors to measure thermal infra-red radiations coming from different land covers. Sensors that record spectral response of land covers are not limited only to thermal radiation and record response at other wavelengths as well. Measured radiations of these sensors are widely used to estimate Land Surface Temperature (LST) and to study biophysical behavior of target objects/land covers. Early researches in this regard, due to coarse spatial resolution of satellite data, have used aerial photographs to identify and characterize MSW piles using their texture and spectral response (Erb et al., 1981; Lyon, 1987; Bagheri and Hordon, 1988; Pope et al., 1996). Modern researches are using Geographic Information System (GIS) along with Digital Image Processing (DIP) of satellite data (Yan et al., 2014). Brivio et al. (1993) have used semivariogram method of spatial autocorrelation and contrast of MSW dumps to their surrounding land covers to delineate them as separate identities. Other analyses make use of spectral mixture modeling (Tromp and Epema, 1998), principal component analysis (Chikhaoui et al., 2005) and comparison of maps to quantify changes in degradation classes (Li et al., 2007). These analyses weresuccessfully used for explaining spatial changes in land-use classes, but quantification of their gradual degradation is much more important which these are not capable to extract (Röder et al., 2008). This quantification is possible through trend analysis of multiple satellite images having sufficient spatial resolution and captured at different times (Lambin and Linderman, 2006; Udelhoven, 2011).

Remote sensing techniques are not limited to LST measurements and are in use to map vegetation health that can be used as an indicator of Landfill gas emission (Jones and Elgy, 1994; Im et al., 2012). Characterization of vegetation cover around MSW dumping facilities using leaf area index, vegetation type, canopy reflectance and normalized difference vegetation index are appropriate to study existence of methane (Noomen et al., 2008, 2012; Im et al., 2012). In addition to multi spectral satellite images, Synthetic Aperture Radar (SAR) is also in use for identifying waste sites (Ottavianelli, 2007).

Use of Landsat time series data is already well established for the Bio-thermal investigation of MSW dumps by mapping Land Surface Temperature (LST) and vegetation indices (Kwarteng and Al-Enezi, 2004; Yang et al., 2008; Shaker et al., 2010; Yan et al., 2014). It is intended to evaluate environmental implications of open dumping of MSW using Landsat 8 data in the present study.

2. Material and methods

2.1. Study area

This study has been undertaken for Faisalabad which is the second largest industrial city of Pakistan. With an area of about 1496 km^2 and an approximate population of 2.86 million, it lies between longitudes 72.8–73.3°E and latitudes 31.15–31.63°N (WGS84) and an average altitude of 186 m above mean sea level. The climate of Faisalabad is hot and semi-arid with an average rainfall of 480 mm per year, peak rainfall is in the months of July and August, with an average of about 200 mm. On average, the maximum temperature found in summer (May to September) is 310.8 K with peak in June (313.7 K) and average of the minimum temperature found in winter (November to March) is 281 K with lowest in January (277.4 K). Being an industrial hub, the city of Faisalabad has about 3000 small, medium and large industrial units mostly dealing with the textile production.

MSW generation rate is figured out as 0.48 kg/capita/day with main components as food waste, demolition/construction waste, paper and cardboard etc. The city does not possess a single scientifically managed waste disposal site. MSW is disposed off in a crude and primitive way. This practice creates complex and serious environmental problems, and grave consequences to public and vegetation health. At present there are two officially announced dumping sites, a main and relatively old dump site and a new young dump about a kilometer away from the old one as shown in Fig. 1. Main dump is the first government owned dumping facility in Faisalabad, lying at 31.386°N and 73.242°E, where MSW dumping started in 2003. It has an area of 140,580 sq. m and a dumped MSW of about 120,000 ton. New dumping facility at 31.398°N and 73.252°E is the proposed location by local government for constructing a proper engineered landfill but open dumping practice has already started. The area occupied by it till this time is about 69,000 sq. m, covered by a waste of about 59,500 ton.

All the dumping of MSW in Faisalabad is currently carried out without any lithological barrier to prevent leachate percolation. There is no closure cover activity, no MSW gas collection system, ultimately no prevention for the protection of local environment. These twin dumping facilities are surrounded by agricultural land that is in use for cultivation of wheat, rice and sugarcane. Agriculture is fully dependent on canal water as the local groundwater is not suitable due to high salinity. The water is provided by sub branch of Lower Chenab Canal (East) originating from river Chenab, one of the five rivers of Punjab province.

2.2. Datasets and study scheme

LandSat 8 data had been used in the study for the temporal window starting from April 2013, when the satellite sensors got operational and started delivering data. Row 038 and path 149 is the index reference of the image where the study area falls. 59 satellite