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Bio-thermal effects of open dumps on surroundings detected by remote sensing—Influence of geographical conditions

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ABSTRACT

This study has used remotely sensed data of Landsat-8 for monitoring open dumps of Municipal Solid Waste (MSW) using vegetation health as a bio-indicator and thermal emissions from it. Open dump of Mahmood Booti has been found to affect the surrounding vegetation up to 800 m in dry summers and reducing to 400 m in winters, while averaging to a distance of about 650 m. Average thermal influence zone has been observed to have same radial extent of about 650 m varying between the minimum of 350 m in dry summer and maximum of 1000 m in winter. All the corresponding details of bio-indicators and temperature variations have also been discussed. In addition to this, the results and methodology of spatial analysis for Mahmood Booti dump of Lahore, Pakistan, surrounded by a heterogeneous land cover, have been compared with the main dumping facility of Faisalabad, Pakistan, which is surrounded by a homogeneous vegetation cover all around. This comparison yielded two main conclusions, first, the surrounding geography of an open MSW dump affects the severity of bio-thermal effects, in addition to waste age, characterization, pile etc. Second, GIS analysis for studying bio-thermal effects requires modification that varies for prevailing neighborhood land cover conditions of MSW open dumps. Use of remotely sensed data for monitoring dumped MSW is a good alternative but selection of proper GIS methodology, representing natural setting of phenomena is equally important as that of the accuracy of the remotely sensed data.

1. Introduction

1.1. MSW open dumps and environmental impacts

One of many problems associated with urbanization and improved living standards is the ever increasing amount of municipal solid waste (MSW) generation. Dumping has always been considered as the final solution for its management (Mahmood et al., 2016). Generally, MSW disposal sites are provided with many engineered systems for environmental protection and are named as landfills. These include lithological barrier to leachate, closer cover, leachate and gas collection systems etc. (Yan et al., 2014). Existence of non-engineered MSW dumping facilities is a very common situation in the developing world (Mahmood et al., 2016). A significant damage to the quality of nearby soils, air and underlying aquifer by open dumping of MSW has been reported (Bellezoni et al., 2014). Hazardous effects of open dumping of MSW on surrounding soil and vegetation, using in-situ sampling and laboratory analysis have been studied by Ali et al. (2014). Values of pH, TDS, electric conductivity, concentrations of Pb, Cu, Ni, Cr, and Zn have been found high at the disposal sites in comparison to control sites (Ali et al., 2014). These pollutants permeate the surroundings of MSW dump at the cost of vegetation health (Ali et al., 2014; Bellezoni et al., 2014). The release of metals from MSW degradation changes the soil chemistry and affects vegetation health (Shaylor et al., 2009). Pollutants resulting from degradation of dumped MSW initiate invisible injury to crops by disturbing plant metabolism that leads to visible degradation later on (Ali et al., 2014). The poor soil fertility results in physiological disorders of plants, leading to irreversible damage to their vigor and growth (Phil-Eze, 2010; Ali et al., 2014). Spread of these pollutions from dumps are highly dependent on flow directions of leachate mixed ground water and prevailing winds (Mahmood et al., 2013, 2015).

Heat energy is another byproduct of MSW decomposition as widely

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reported in literature e.g. Faitli et al. (2015), (Vaverkova and Adamcova (2015); Hanson et al. 2008, 2010, 2013), Mahmood et al. (2016). Thermal conditions are a measure of rate of waste decomposition along with the chemistry of leachate and gasses emitted at MSW dumping facility (Hanson et al., 2010; Bo-Feng et al., 2014; Mahmood et al., 2016). Reduced emissions of methane by its oxidation with an increase in temperature has been reported (Bo-Feng et al., 2014). Heat generation by MSW dumps is also responsible for the formation of a microclimatic zone around the dump site that results into many local environmental implications (Mahmood et al., 2016). This heat generated is somehow analogous to Urban Heat Island (UHI). Urban areas have higher temperature in contrast to their surroundings because of greater absorption and re-emission of heat energy due to concreate structures and other human activities (Liu et al., 2009; Sajjad et al., 2015). UHI depends on sunlight and therefore it varies with seasonal temperatures, whereas heat generated through MSW dumps not only depends on seasonal temperatures but also on other factors such as waste age, composition, amount etc. An increase in environmental temperature affects human health in terms of general discomfort, heat cramps, non-fatal heat strokes etc. (Tan et al., 2010). Old people, children and those with poor health conditions are more prone to such overheated conditions.

1.2. Overview of remote sensing techniques

There has been an increase in the use of remotely sensed satellite data as a substitute of expensive and time consuming ground based measurements in environmental studies (Mahmood et al., 2016). Remote sensing provides a synoptic view of Earth's topography along with the facility to survey a large area in a short time and its applications encompass a wide range of geographic and environmental issues (Yan et al., 2014; Ul-Haq et al., 2015a,b; Mahmood et al., 2016). Sensors onboard different satellites are designed to record spectral response of underlying topography and categorize them on the basis of their spectral signatures that ideally differ from each other (Erb et al., 1981; Yan et al., 2014). Delkash et al. (2016) have made use of remotely sensed satellite data to estimate emissions of landfill methane and the results were successfully verified with ground measurements. These agreements between results from remotely sensed satellite data ground based observations are encouraging for the use of this technique as a feasible alternative to ground measurements.

Presently a number of satellites provide remotely sensed data that is used for land cover assessments and undergone temporal changes (Glanville and Chang, 2015). For environmental sustainability and management studies, preference has been given to the satellite data with better spatial resolutions i.e. ALOS AVNIR-2 (10 m), FORMASAT-2 (2 m), IKONOS (0.82 m), QUICKBIRD (0.65 m), ALOS PRISM (2.5 m) (Glanville and Chang, 2015). During the last decade, satellite based remote sensing has entered into a new era, where global environmental data sets are available with the parent organization deriving information from satellite imagery. Aqua and Moderate Resolution Imaging Spectrometer (MODIS) onboard Terra are examples of such products (Ul-Haq et al., 2015a,b). Products provided by such platforms, having coarse spatial resolutions, are generally meant for large scale studies and their use for local environmental monitoring is still not very feasible.

For localized studies, Landsat data with a spatial resolution of 15 m and a temporal resolution of 16 days have also been effectively used (Rajeshwari and Mani, 2014; Yan et al., 2014; Mahmood et al., 2016). Landsat-8 data, with improved spectral resolution, more specific bandwidth and a better radiometric resolution have become even more accurate and reliable (Li et al., 2014). The use of this data is also preferred for providing free historical archives over the last four decades. Applications of current Landsat data are not only available for optical bands but, due to increased spatial and radiometric resolutions of thermal bands, measurement of Land Surface Temperature (LST) has become more precise, with many algorithms devised by different researchers. Frequently used models for LST estimation in arid and semi-arid regions are Dual Angle, Split Window, Mao, Sobrino and Sobmao (Rajeshwari and Mani, 2014). Use of Landsat-8 data to derive LST, using Split-Window (SW) algorithm with Thermal Infrared Sensor (TIRS) and NDVI (derived from Operational Land Imager (OLI) bands) is explained by Rajeshwari and Mani (2014). Similarly, Bhandari et al. (2012) have reported a study using time series of Landsat images to monitor changes in phenology of vegetation.

1.3. Remote sensing for monitoring of MSW dumps

Shaker et al. (2010) have given a brief description of possible use of remote sensing techniques and data sets for monitoring MSW dumping. A similar kind of review has been published by Hannan et al. (2015) where the authors have also reviewed the use of GIS and GPS data integrated with remote sensing to enhance its capability. More recent studies are also using remote sensing data for assessing temperatures and bio-hazards, linked with the MSW open dumps (MSWOD) (Lacoboaea and Petrescu, 2013; Mahmood et al., 2016). The few examples include Kwarteng and Al-Enezi (2004); Im et al. (2012); Lacoboaea and Petrescu (2013); Yan et al. (2014) and Mahmood et al. (2016). Kwarteng and Al-Enezi (2004) have done a preliminary work using several satellite remote sensing data sets i.e. Landsat, IKONOS, and Synthetic Aperture Radar (SAR), reporting higher surface temperatures of landfill in comparison to surroundings that supplements release of landfill gases by accelerating biodegradation of dumped waste. Such datasets, if incorporated in GIS, could enhance the detail of extracted information using spatial and temporal analyses. Im et al. (2012) have used hyperspectral remote sensing to study vegetation cover over landfill sites. Lacoboaea and Petrescu (2013) have used remotely sensed data of Landsat-5 Thematic Mapper (TM) and Landsat-7 Enhanced Thematic Mapper Plus (ETM^+) for monitoring temperature of different waste disposal zones in a MSW landfill. Yan et al. (2014) have successfully used time series Landsat images to measure temperatures of different landfill sites that was found to be higher than surrounding vegetation by 4–10 K and air by 5–11 K. All studies confirmed and recommend the use of Landsat data as a complementary source for monitoring MSW dumps. Recently Landsat-8 imagery has been successfully utilized by Mahmood et al. (2016) to study increased temperature of MSW dump in comparison to nearby agriculture and residential area. The addition of GIS proximity analysis has enabled Mahmood et al. (2016) to study effect of MSW degradation on neighborhood temperatures as well. In this study, thermally influenced neighborhood of MSW dump was mapped to surrounding on an average 700 m radial zone varying from 500 m in spring to 1100 m in monsoon. Vegetation health had also been mapped and used as a bio-indicator of MSW dumping hazards. The area selected by Mahmood et al. (2016) was very homogeneous and the dumping site was surrounded with the same seasonal crops throughout the study period, making proximity analysis simpler.

The existence of heterogeneous land cover around MSWOD demands modifications in such simple GIS analysis. Geographical differences making land cover more heterogeneous may include urbanization patterns, inconsistent crop patterns, nearby existence of other sources of pollution etc. The main objective of this study is to assess bio-thermal influence on surroundings at Mahmood Booti MSWOD and to compare the results and methodologies with that of Faisalabad's main MSWOD.

2. Materials and methods

2.1. Study area

In the present study we have compared two open dumps situated in the cities of Lahore and the other in Faisalabad. Both the cities belong to Punjab province of Pakistan and are categorized as semi-arid regions.