Satellite Remote Sensing and Image Processing Techniques for Monitoring MSW Dumps

Fiza Faizi1, Khalid Mahmood2*, Muhammad Hamid Chaudry1, Asim Daud Rana2

Abstract

The synoptic perspective of satellite borne remote sensors can prove to be of great value in the fields of waste management and remediation, which require cost effective and timely information from space monitoring techniques. At present, there exists a gap in literature regarding monitoring and assessment of Municipal Solid Waste (MSW) dumps using image processing techniques on satellite data. This study intends to analyze the effectiveness of remotely sensed satellite images and existing classification techniques, based on spectral analysis, to bridge this gap. In this study, medium resolution remotely sensed satellite datasets such as Landsat-8 as well as Sentinel-2 have been used to explore the potential use in waste monitoring and management. The study aimed at both the accurate mapping/classification as well as development of a rigorous validation approach for MSW disposal sites in Faisalabad, Pakistan. Both of these objectives have been met with significant success using tools of image processing and GIS technology. Pixel based image classification strategy in supervised and unsupervised domains was adopted to extract landcover information. According to the accuracy assessment results, with a percentage accuracy measure of 94.82% Sentinel-2 supervised classification stands at the first position closely followed by Sentinel-2 unsupervised classification at the second place with a percentage accuracy of 92%. Landsat-8 unsupervised classification is ranked at the third position with 85% accuracy, whereas, Landsat-8 supervised classification fills the position at the bottom with 73.61% accuracy of its classification output. From these results, it can safely be assumed that high spatial resolution and richness of spectral content lead to more accurate results in hazardous MSW open dumps identification and monitoring.

Keywords: Classification, Image Processing, MSW Landfill, Spectral Analysis, Waste Monitoring.

1. INTRODUCTION

The impact assessment of various natural and anthropogenic phenomena on our surrounding environment requires timely and accurate information for correct decision making [1]. Due to ever-increasing demand of geospatial data in recent years, the exploration of new means by which such data could be generated seems critical. The information derived from this data helps supplement resource inventories throughout the globe. Constraints of cost and time have led to exercising use of new technological innovations such as remote sensing derived products, computer processing techniques and novel statistical estimation procedures [2].

The increasing magnitude and scale of environmental challenges beforehand, and the shift in spatial domain of such problems from local to synoptic and even global has resulted in a dire need of geospatial information by governments as well as administrative agencies throughout the world [3]. With the advent of airborne/space borne imaging platforms in recent times, the effectiveness and appropriateness of remotely sensed data for
environmental studies has frequently been reported [4]-[6]. Remote sensing and image processing techniques prove to be particularly useful for monitoring the environment [1],[3]-[5], [7]-[8]

2. MATERIAL AND METHODS

The study has been done for MSW sites of Faisalabad with a population of about 2.86 million [9]. Spatial settlement of the area is shown in figure 1.

MSW Open dumping sites from remotely sensed data and the outputs were subject to post classification processing in a GIS environment. Unsupervised classification is performed using Iterative Self Organizing Data Analysis Technique (ISODATA) that makes cluster of land covers on the basis of spectral response in n-dimensional space, whereas, the supervised classifier used is Maximum Likelihood Parametric (MLP). Further scrutiny has been made using knowledge based restriction rules. In order to evaluate the performance of supervised and unsupervised algorithms, an appropriate accuracy assessment procedure was carried out. To extract useful thematic information from remotely sensed data, Multispectral image classification is among the most widely used methods. The images captured in multiple and non-overlapping parts of the electromagnetic spectrum are assumed to be in sound geometric registration with one another [10]-[11].

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum number of classes</td>
<td>70</td>
</tr>
<tr>
<td>Minimum cluster size in percentage</td>
<td>0.01%</td>
</tr>
<tr>
<td>Maximum Standard deviation allowed for a cluster</td>
<td>2.95</td>
</tr>
<tr>
<td>Minimum spectral distance between clusters</td>
<td>4</td>
</tr>
<tr>
<td>Maximum merges in an iteration</td>
<td>1</td>
</tr>
<tr>
<td>Maximum number of iterations</td>
<td>10</td>
</tr>
<tr>
<td>Convergence Threshold</td>
<td>0.950</td>
</tr>
</tbody>
</table>

Table 1. Unsupervised classification parameters and values

A variety of algorithms can be employed to achieve the objective of classification and mainly fall into two categories i.e. hard classifiers and soft classifiers. Hard classification scheme encompases the domain of Supervised Classification and Unsupervised Classification and assumes that each pixel in the image can belong to one information class only [10]-[11]. In an unsupervised classification scheme (Table 1), due to absence of a priori knowledge of the study area or lack of well-defined surface features in a remotely sensed scene, the
computer is required to classify the pixels by clustering them in unique groups following certain statistical parameters. Relabeling of features is then carried out by the image analyst into hard information classes.

In supervised classification scheme (Table 2), the image analyst recognizes certain homogenous land covers captured in the remotely sensed image and through a combination of ground truthing, field reference data, a priori knowledge and previous personal experience, assigns the pixels relating to these landcovers as part of training areas. These pixels are subsequently used to train a hard classification algorithm that evaluates the likelihood of membership of other pixels in the image to the well-known training area classes.

<table>
<thead>
<tr>
<th>CLASS NAME</th>
<th>SIGNATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation</td>
<td>17</td>
</tr>
<tr>
<td>Soil (dry)</td>
<td>10</td>
</tr>
<tr>
<td>Soil (wet)</td>
<td>8</td>
</tr>
<tr>
<td>Residential area</td>
<td>7</td>
</tr>
<tr>
<td>Water</td>
<td>6</td>
</tr>
<tr>
<td>Open MSW dumps</td>
<td>5</td>
</tr>
</tbody>
</table>

In both the cases of Unsupervised or Supervised classification, a procedure of rigorous error evaluation must be performed in the end, so as to ascertain the acceptability and accuracy of the results derived from the final classification map. In order to improve the accuracy of classification, user knowledge and ancillary data can be incorporated in a GIS environment during post classification processing steps.

Figure 2. Unsupervised Classification Result of Sentinel-2 MSI image

Figure 3. Unsupervised Classification Result of Landsat-8 OLI image
General layout of the methodology is given in figure 4.

3. RESULTS AND DISCUSSIONS

In this section we discuss the relative differences in spectral reflectance curves of wastes with varying degree of freshness. As recorded by Landsat-8 OLI sensor, some of the classes of Municipal Solid Waste having different ages of disposal are illustrated in the figure 5. The discussion on each of the spectral curve follows the illustration.
Satellite Remote Sensing and Image Processing Techniques for Monitoring MSW Dumps
Fiza Faizi, Khalid Mahmood, Muhammad Hamid Chaudry, Asim Daud Rana

In the above figure, MSW 1 represents the freshest waste disposed in the MSW landfill sites of Faisalabad. It ages to about 5 years old. It has the lowest reflection values among the whole spectrum of signatures. MSW 2 represents waste of intermediate age i.e. 5-10 years old waste. It has relatively higher spectral reflectance pattern than the fresh waste MSW 1. MSW 3 and MSW 4 are the oldest wastes disposed of in the landfill sites and are more than 10 years old. It can be deduced from the spectral curves of these wastes that the degree of freshness and moisture content in the disposed waste largely control the reflectance pattern. Fresh wastes that have coarse texture and high level of moisture content have low reflectance in general. The large grain sizes cause low scattering and reflection of energy in the visible wavelengths. The high amount of water molecules cause absorption in the infrared part of the electromagnetic spectrum. In contrast, older wastes which have very fine grain sizes due to a great amount of disintegration and decomposition undergone by these and having depleted of their water content reflect higher than the fresh waste.

The spectral reflectance curves of wastes of varying ages as sensed by Sentinel-2 MSI are shown the following figure (figure 6). The discussion on each of the spectral curve follows the illustration.

In the above figure, MSW 1 represents the freshest waste disposed in the MSW landfill sites of Faisalabad aged up to 5 years old. MSW 2 and MSW 3 curves correspond to wastes aged between 5 to 10 years. It was noted that their spectra mix with concrete structures i.e. road and residential areas. MSW 2 has more spectral mixing with roads whereas MSW 3 has more spectral resemblance to residential area. MSW 4 contains some patches of the oldest waste having disposal age between 10-15 years. MSW 5 and MSW 6 contain most of the part of oldest (10-15 year old) waste. These spectral classes have high tendency of being mixed with rural residential areas. MSW 7 largely represents the spectral curve of rural residential area and only few pixels of the oldest waste. The old wastes reflect higher than the fresh wastes and explanation of this behavior has already been given.
4. CONCLUSIONS

The study has established the use of satellite data for monitoring MSW dumps using both supervised and unsupervised classifiers, filling existing gap in the literature. These classifiers have been tested on two different satellite data sets 1) Landsat-8 2) Sentinel-2.  Hierarchy of accuracy achieved is 94.82% for Sentinel-2 with supervised classification; 92% also for Sentinel-2 with unsupervised classification; 85% is for Landsat-8 with unsupervised classification and 73.61% also for Landsat-8 but with supervised classification. Overall, Sentinel-2 data with greater spatial resolution has been found better than Landsat-8, whereas, unsupervised classification has provided better results than that of supervised classification. Moreover, Landsat-8 data suffered from misclassification errors arising due to sensor saturation effects near bright saline surfaces. It was also noted that the complexity of signatures arising due to mixed landscapes in rural surroundings can be more efficiently addressed using high resolution satellite data. This comparison of different data sets under different classifiers has also been extended for segregation of dumped waste on the basis of its dumping age. For this segregation an additional aid of information has been obtained from spectral response curves. Therefore, the study highly recommends the use of remotely sensed data of superior spatial and spectral resolutions that may enhance the spectral differences among dumped solid waste and other land covers. So satellite data with best available spatial resolution and computer assisted automated algorithm are highly recommended for identification as well as studying properties of openly dumped MSW.

ACKNOWLEDGEMENT

We are thankful to the support provided by HEC, Pakistan under the project development of satellite based environmental indices with proper spatial analysis for dumped MSW monitoring: perspective of varying geographical conditions.

REFERENCES


BIOGRAPHY

Fiza Faizi works as a volunteer researcher at Remote Sensing, GIS and Climatic Research Lab, Department of Space Science, University of the Punjab.

Fiza Faizi received her Gold Medal in Graduation in the year 2014 from Department of Space Science, University of the Punjab, Pakistan, and again a Gold Medal in Masters in GIS and Remote Sensing in 2018 from Centre for GIS, University of the Punjab, Pakistan. She is engaged in active research in the field of Environmental applications of Geospatial technologies particularly Municipal Solid Waste monitoring and identification.

She may be contacted at fiza.faiizi.spse@gmail.com