Electromagnetic Survey (GEM-2) for Monitoring of an Open Dumpsite in Sri Lanka

S. Kamaleswaran¹, P.P. Udayaghee KumaraSinghe¹, M.I.M. Mowjood², M. Nagamori³, Y. Isobe³, Y. Watanabe³, G.B.B. Herath⁴ and K. Kawamoto⁵

¹Postgraduate Institute of Agriculture, University of Peradeniya
Peradeniya, Sri Lanka

²Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya
Peradeniya, Sri Lanka

³Center for Environmental Science in Saitama
914 Kamitanadare, Kazo, Saitama 347-0115, Japan

⁴Department of Civil Engineering, Faculty of Engineering, University of Peradeniya
Peradeniya, Sri Lanka

⁵Institute for Environmental Science and Technology
Graduate School of Science and Engineering, Saitama University
255 Shimo-Okubo, Sakura-ku, Saitama 338-8570, Japan

e-mail: mmowjood@pdn.ac.lk

Abstract: Open dumping of municipal solid waste creates series of environmental and social problems. Monitoring of dumpsites is important in deciding and designing the mitigation measures to reduce the risk. Direct and continuous monitoring of dumpsite is difficult and requires time, money and labour for both sample collection and laboratory analysis. Geophysical methods such as electromagnetic (EM) technique can be used for subsurface investigation rapidly without in-situ drilling and sampling. GEM-2 is a Multi-frequency, handheld EM sensor. This produces EM waves at pre-set multi frequencies and receives secondary EM waves from eddy current of substrate depending on the apparent electrical conductivity (ECa) of the substrate. Thus ECa of the underneath substrate can be mapped. An open dumpsite in Udapaltha Pradeshiya Sabha, Central province, Sri Lanka was surveyed using GEM-2 and validated with field measurement. For validation, waste samples were collected up to 30 cm depth and electrical conductivity (EC) was measured at the laboratory and ECa was calculated. Spatial and temporal variation of ECa and delineation were clearly depicted in maps produced by GEM-2. Maximum reported ECa in Old-bottom and New-top of dump site were 88 mS/m and 180 mS/m, respectively. Measured ECa and EM surveyed ECa were correlated with simple linear regression. Best correlations were obtained at Old-bottom with 93 kHz wave length while 85 kHz for New-top. It can be concluded that EM survey is a powerful technique for dumpsite monitoring with cautious interpretation.

Keywords: Apparent electrical conductivity, Electromagnetic survey, Municipal solid waste, Open dumpsite.

1 INTRODUCTION

Municipal Solid Waste (MSW) has been identified as one of the major pollution problems of the world, and become one of the major challenges in developing countries. Most common disposal method of MSW in Sri Lanka is open dumping. Wastes in dumpsites undergoing decomposing processes results in several organic and inorganic substances. Most of these compounds leave the dumpsite as leachate and gas and pollute the environment.
The open dumpsites have to be monitored for better management since the gas emission and leachate generation varies spatially and temporally. Conventional monitoring of MSW dumpsite required drilling, sampling and laboratory analyzing that costs and time consuming. Investigation on spatial and temporal variation is also difficult with spot measurements.

In this context, the geophysical methods such as Electromagnetic (EM), Ground penetrating radar (GPR), Seismic refraction, Electrical resistivity, Gravity, Borehole geophysical logging. Induced polarization and Thermal infrared are used to monitor and evaluate the dumpsites features (McDowell, et al 2002; McGinnis, et al 2011, Ayolabi, et al 2013). Geophysical methods are best options to investigate the dumpsites, because of effective sampling strategy, reduced assessment cost as reducing the number of borings/wells needed and investigating large area(Zungalia, et al 1989; Letellier, 2012; Wijesekara, et al 2014). These methods are generally used in preliminary investigations with verification of direct method. However geophysical data interpretation is quite difficult and needs special expertise (Sharma & Reddy, 2004). High initial capital investment is one of the main factors hindering the wider use of this technology in landfill survey in Sri Lanka.

Apparent electrical conductivity ($EC_a$) is the depth weighted average of the bulk soil electrical conductivity. It can be measured in both ways such as contact and non-contact methods. It is commonly measured by using EM techniques (Cook & Walker, 1992). $EC_a$ is good indicator of soil physical and chemical properties. GEM-2 is a handheld, digital, programmable, multi-frequency, broadband EM sensor which widely uses to geological, environmental and geotechnical surveys. This sensor produces EM waves at pre-set multi frequencies and receives secondary EM waves from eddy current of substrate depending on the $EC_a$ of the substrate. Thus $EC_a$ of the underneath substrate can be mapped. Open dumpsites in Sri Lanka are rarely monitored by geophysical methods, due to its availability and validation. This study was conducted to reveal the applicability of EM survey in an open dumpsite at Udapalatha.

**2 METHODOLOGY**

**2.1 Study area**

An uncontrolled landfill in Udapalatha Pradeshiya Sabha (PS), central province, Sri Lanka was selected for the study. It is located at 7° 08' 40.8" N and 80° 34' 43.2" E and at altitude of 492 m amsl (above mean sea level). The site is at a steep slope towards the Mahaweli River from the Gampola-Kotmale Road with 15 m elevation difference within 50 m length. The dumpsite has two sections: Old and New with 7 and 0.5 years of operation, respectively. The municipal waste collected from the Udapalatha Pradesheya Shabha and Gampola Urban council were dumped until 2011. The site was not in operation for last 3 years and the land was covered by vegetation during the study period.

Comparatively flat areas at the bottom of old section (Old-bottom) and top of new section (New-top) were selected for EM survey (Figure 1). Old-bottom was nearby the Mahaweli River and New-top was more close to the main road. Both areas have been cleared from vegetation and interrupting materials.

*Figure 1 Dump site and locations GEM survey*
2.2 GEM-2 Electromagnetic Survey

As shown in Figure 2, selected areas were divided into grids and the grid lines were marked with a spacing of 1 m. Survey area with the dimensions of 8 x 2 m and 11 x 4 m at Old-bottom and New-top, respectively, were marked. The base period for the sensor was selected according to power line of the area. Therefore 25 Hz was selected for 50 Hz power region. The output sample rate is 10 Hz. Other inputs for GEM-2 such as coil separation and sensor height were 1.66 m, and 1 m, respectively. Frequency of the EM waves has to be specified by the users. Using more than five frequencies simultaneously is not recommended, because of power being distributed equally between frequencies. High number of frequencies may weaken the signal. Therefore, five frequencies, 55, 65, 75, 85 and 93 kHz were selected at a time for the survey (maximum frequency that can be used from the GEM-2 was 93).

The survey was conducted on 3 days (13th, 24th November and 2nd December 2014). GEM-2 was hold horizontally and surveyed starting from line 1 and walked steadily along the line then stopped at end of the line 1. Automatically the data were stored in the SD card memory as well as internal memory of the GEM-2. U-turn was taken at end of the line 1 and repeated the same along the line 2, continued the same until finish the survey as shown by Figure 2.

Data was downloaded and converted as .CSV file using EM Export software. Quadrature data were converted to ECa using Invertor software. The ECa variation was plotted in the horizontal plane by Surfer 11 for each frequency.

2.3 Field Sampling and Analysis of EC

Waste sampling points were selected for validation at both sites, based on the horizontal map generated by GEM-2 at preliminary test. The samples were collected on 13th November 2014 in five points within the survey area up to the depths of 15 and 30 cm from the surface. Electrical conductivity (EC) was measured in the SATREPS Environmental Laboratory, Faculty of Engineering, University of Peradeniya using standard method (Allison, et al 1954). Measured EC at different depths were used to calculate depth weighted EC as apparent EC. The ECa from both GEM-2 and field measurements were correlated. The linear regression analysis was done for both old and new sections, separately.

2.4 Measurement of Rainfall

Daily rainfall was measured from the weather station at Meewathura farm, University of Peradeniya, Peradeniya during the study period.

3 RESULTS AND DISCUSSION

3.1 Rainfall During the Study Period

Figure 3 shows the daily rainfall from 12th November to 2nd December 2014. The rainfall varied between the surveys. It is reported that ECa varies with the moisture content of the substrate (Grellier et al 2007).
3.2 Spatial and Temporal Variation of $E_{Ca}$

GEM-2 EM sensor measures $E_{Ca}$ at multiple frequencies and magnetic susceptibility at the lowest selected frequency (Geophex Limited, 2004). The survey produces raw data as quadrature and in-phase components representing $E_{Ca}$ and magnetic susceptibility, respectively (Won et al 1996). $E_{Ca}$ maps for each frequency were shown figure 4 and 5. Each frequency map represents a horizontal layer up to a depth. Lower the frequency the higher the layer thickness surveyed.

Figure 4 shows the $E_{Ca}$ variation at 85 kHz frequency in both sites on 3 days. Lower $E_{Ca}$ was observed towards river side in Old-bottom. Higher $E_{Ca}$ was observed towards the river in New-top. This may be due to the difference in the stage of waste stabilization process between old and new sites. The temporal variations were able to observe with the GEM-2 EM survey maps on 3 days.

Figure 5 shows the $E_{Ca}$ maps with 5 different frequencies for old and new site on 2nd December 2014. Horizontal layers at different depths of dumpsite are depicted. Shallow depth has higher $E_{Ca}$ compared to deeper layers. There is a consistency in the spatial variation in $E_{Ca}$ as the thickness of the survey increased. The compactness of the waste layers in the landfill sites may be one of the reasons for the $E_{Ca}$ variations although it was not measured in this study.

Figure 4 Temporal variations $E_{Ca}$ with the frequency of 85 kHz (a) Old-bottom and (b) New-top
3.3 Validation of GEM – 2 EM survey

Depth weighted EC measured at the laboratory was correlated with EC$_a$ at each frequency maps of GEM-2. Figure 6 shows the correlation for Old-bottom (a) and New-top (b). In both sections, high correlation was obtained in all frequencies tested (Table 1 and 2). Best correlations were obtained at Old-bottom and New-top with 93 kHz and 85 kHz wave length, respectively.

Old site has low EC thus high resistivity than new site. Wave penetrates deeper in high resistive site than low resistive site. The Old site has high resistivity so that 93 kHz EC$_a$ was correlated at 30 cm depth weighted average EC. New site has lower resistivity than old site thus 85 kHz EC$_a$ was correlated at 30 cm depth weighted average EC.

(a)

(b)

Figure 6 Correlation of EC$_a$ from GEM - 2 and laboratory (a) Old-bottom (b) New-top
## Table 1. Simple linear regression output of Old-bottom

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Depth 15 cm</th>
<th>Depth 30 cm</th>
<th>Depth weighted avg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R^2$ (%)</td>
<td>P-value</td>
<td>$R^2$ (%)</td>
</tr>
<tr>
<td>93 kHz</td>
<td>70.5</td>
<td>0.075</td>
<td>77.6</td>
</tr>
<tr>
<td>85 kHz</td>
<td>64.1</td>
<td>0.104</td>
<td>75.8</td>
</tr>
<tr>
<td>75 kHz</td>
<td>65.5</td>
<td>0.097</td>
<td>74.9</td>
</tr>
<tr>
<td>65 kHz</td>
<td>62.6</td>
<td>0.111</td>
<td>72.9</td>
</tr>
<tr>
<td>55 kHz</td>
<td>60.1</td>
<td>0.123</td>
<td>73.6</td>
</tr>
</tbody>
</table>

## Table 2 Simple linear regression output of New-top

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Depth 15 cm</th>
<th>Depth 30 cm</th>
<th>Depth weighted avg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R^2$ (%)</td>
<td>P-value</td>
<td>$R^2$ (%)</td>
</tr>
<tr>
<td>93 kHz</td>
<td>78.5</td>
<td>0.045</td>
<td>73.5</td>
</tr>
<tr>
<td>85 kHz</td>
<td>59.9</td>
<td>0.124</td>
<td>89.6</td>
</tr>
<tr>
<td>75 kHz</td>
<td>59.0</td>
<td>0.129</td>
<td>88.2</td>
</tr>
<tr>
<td>65 kHz</td>
<td>58.4</td>
<td>0.132</td>
<td>87.5</td>
</tr>
<tr>
<td>55 kHz</td>
<td>52.5</td>
<td>0.166</td>
<td>91.5</td>
</tr>
</tbody>
</table>

### 4 CONCLUSIONS

Spatial and temporal variation of ECₐ was mapped using GEM-2 with different frequencies. Waste distribution and delineation of dumpsite were clearly depicted on horizontal plane maps with different layers in both Old-bottom and New-top of Udapalatha dumpsite. Maximum exhibited ECₐ in Old-bottom and New-top were 88 mS/m and 180 mS/m, respectively by EM survey. GEM-2 EM surveyed ECₐ was highly correlated with weighted average EC which was calculated using measured EC of waste samples at the depth of 15 and 30 cm in both sites. Best correlation was found with 93 kHz and 85 kHz wave length for Old-bottom and New-top, respectively. This may be due to differences in characteristics between old and new sections of the dumpsite. GEM-2 EM sensor can be used for waste stratification of dumpsite with careful interpretation. Detail site investigation can be carried out by incorporate with other geophysics technique.

### 5 ACKNOWLEDGMENTS

This work was supported by Science and Technology Research Partnership for Sustainable Development (SATREPS) Project funded by Japanese International Cooperation Agency (JICA) and Japan Science and Technology agency (JST), Japan.

### 6 REFERENCES


