Spectral Reflectance Curves of Waste at Landfill Sites in Vietnam

Kosuke KAWAI[1*] and Ryoji KAWATA[2]

[1] *Material Cycles Division, National Institute for Environmental Studies*
16-2 Onogawa, Tsukuba-shi, Ibaraki 305-8506, Japan
[2] *Engineering Office for Remote Sensing, Kankyo Techno Co., Ltd.*
1-29-10-8 Hamamatsucho, Minato, Tokyo 105-0013, Japan
**E-mail: kawai.kosuke@nies.go.jp*

Abstract

With increasing amounts of waste being generated in developing countries, landfill capacity shortages are becoming apparent. As a result, there are concerns that the number of open dumping sites managing waste poorly and disposing of waste inappropriately will increase. These sites are not generally government-authorized, and their gas emissions and leachates are not managed at all. Moreover, identifying the locations of open dumping sites is not simple. In this study, we calculated spectral reflectances and recorded spectral reflectance curves of waste, soil, vegetation and leachate from measurements with a portable spectral radiometer in central and southern Vietnam, at landfill sites in Hue and Nha Trang. Even though waste in landfill and dumping sites is heterogeneous, being mixtures of various materials including plastic, paper and food waste, we confirmed that the spectral reflectance curves of waste presented in this study have consistent regularity regardless of measurement point and field of measurement; the spectral reflectance of waste gradually increases from 10% to 40% as the wavelength goes from 350 nm to 850 nm. The results suggest that using satellite data to develop techniques for identifying locations of open dumping sites will be worthwhile and signify that reflectance curves of waste obtained by on-site measurements will be useful as ground-truth data. The study also revealed that spectral reflectance curves of waste are similar to those of soil as the next challenge in detecting the locations of open dumping sites via satellite data.

Key words: developing country, open dumping, satellite data, spectral irradiance, waste management, wavelength

1. Introduction

In developing countries, most waste is disposed of at landfill and dumping sites with no pretreatment. Various environmental and health effects originate from poorly managed landfill and dumping sites, including greenhouse gas emissions (Kawai & Tasaki, 2016; Kaza *et al*., 2018; Singh *et al*., 2021). Although incineration facilities have begun to be introduced in Vietnam in recent years, they do not have the capacity to dispose of all waste, and the country still has no choice but to rely on landfills for stable waste management (Nguyen *et al*., 2021). With economic development and increasing population, the amounts of waste generated are continuously increasing in Vietnam, meaning that landfill and dumping sites are quickly filled up with waste. In particular, it is not easy to find space for new landfill and dumping sites in large cities and their suburbs. Moreover, waste collected in urban areas may be piled up in the open at transfer stations. If these piles become large, they become open dumping sites. Gas emissions and leachates are generally not managed very well at those sites. In the future, as amounts of waste increase in developing countries, there is concern that the number of open dumping sites managing waste poorly and disposing of waste inappropriately will increase. Where a landfill site causes concern about profound environmental and health risks, policies for immediately halting disposal and managing the waste appropriately are necessary. Correspondingly, identifying the locations of open dumping sites and ascertaining their management conditions and environmental and health risks is an urgent matter.

Studies of landfill and dumping sites are being conducted around the world using satellite data. There have been many reports of case studies using mainly optical sensors (Alexakis & Sarris, 2014; Paul *et al*., 2014; Papale *et al*., 2023). For example, there are studies that use satellite data and geographical information

systems (GIS) to reveal distances from landfill and dumping sites to water bodies, urban areas and other sensitive places and evaluate environmental and health risks from those sites geographically (Saatsaz *et al*., 2018; Karakuş *et al*., 2020; Sadhasivam *et al*., 2020). Other studies report using thermal infrared sensors that reveal ground surface temperatures at landfill sites to be remarkably high (Trinh *et al*., 2021). In Japan, Ishizaki *et al*. (2004) and Komiya *et al*. (2006) estimated gas compositions to monitor management conditions at large-scale landfill sites and to develop management techniques using satellite data. Yonezawa (2009) used satellite data to monitor illegal waste dumping in Miyagi Prefecture. The studies mentioned above are all directed at known landfill and dumping sites. Kosako *et al*. (2009) tried using satellite data to detect unknown landfill sites (illegal dumping locations) in Japan. Illegal dumping locations in Japan, however, tend to be concealed, such as by vegetation; so similar research in Japan has not made progress. Kruse *et al*. (2023) used Sentinel-2 satellite data to detect and map landfill and dumping sites in Southeast Asia, particularly Indonesia, and published their results online (https://globalplasticwatch.org/).

Satellite data consist of image data obtained from earth observation satellites that are capable of repeatedly observing large areas of particular regions. The spectral reflectance curves of waste must be acquired for the ground-truth data to detect open dumping sites using satellite data. Spectral reflectance curves can be acquired by using a spectral radiometer on site to measure spectral radiance and irradiance of subjects (below referred to as spectral radiometer measurements) and calculating those spectral reflectances. No studies in either developed countries or developing countries, however, have calculated spectral reflectances of waste from on-site spectral radiometer measurements to acquire spectral reflectance curves of waste for use as ground-truth data.

Waste in landfill and dumping sites is heterogeneous, comprising mixtures of various materials including plastic, paper and food waste. In Vietnam, the amount of waste is rapidly increasing and open dumping sites are increasing in number. Using Vietnam as a case study, the objectives of this study were to conduct spectral radiometer measurements of waste, soil, vegetation, and leachate at landfill sites, calculate their spectral reflectances, verify that the spectral reflectance curves had consistent regularity even though the waste was heterogeneous, and verify that the reflectance curves of waste differed from the spectral reflectance curves of the other substances studied (soil, vegetation and leachate). If consistent regularity is found in the spectral reflectance curves of waste, the data obtained in this study may be used as basic data when satellite data are being used to detect open dumping sites in developing countries.

There are many uncertain factors that make conducting spectral radiometer measurements at landfill sites in developing countries very difficult, such as obtaining survey permits for the sites, traveling to cities' outskirts, and performing activities in unpleasant conditions with waste scattered around. Therefore, to refine methods for acquiring spectral reflectances of waste with precise measurements, we first conducted preliminary surveys on the outskirts of the Vietnamese capital, Hanoi. We then conducted the actual surveys at landfill sites in central and southern Vietnam, in Hue and Nha Trang.

2. Outline of the Preliminary Surveys near Hanoi

We conducted preliminary surveys, taking measurements of waste, soil, vegetation and leachate with a portable spectral radiometer at two relatively small open dumping sites on the outskirts of Hanoi on April 18, 2023 and one open dumping site in Hung Yen Province on April 19, 2023. The spectral radiometer was mounted on a camera monopod, hand-held by an operator, and the substances were measured from heights of about two meters above ground. Since it was important to compare and verify measurement results using the spectral radiometer under as similar conditions as possible, a certain amount of sunlight was required, and measurement under clear skies was preferable. The sky, however, was lightly cloudy when the measurements were made with no direct sunlight. The operator had to move away from measurement points when waste collection vehicles entered the sites. In consequence, the sunlight was not consistent during the measurements, and accurate measurement results were not obtained due to frequent interruption of the measurements under cloudy skies and unstable sunlight. From our experience in the preliminary surveys, we determined that we should obtain survey permits for landfill sites in central and southern Vietnam, where the proportion of days with clear weather is relatively high throughout the year and light intensities are consistent, that we should mount the spectral radiometer on a tripod, and that we should conduct the spectral radiometer measurements quickly. Furthermore, we determined that it would be necessary to secure locations where measurements could be taken under conditions that would not be affected by waste collection vehicles.

3. Materials and Methods

3.1 Measurement Sites

Bearing in mind the problems in the preliminary surveys near Hanoi, in August we conducted measurement surveys with the spectral radiometer in central and southern Vietnam where there was a higher proportion of clear days. The survey sites were the Thuy Phuong landfill site (operating from 1999, landfill area

6.7 ha, receiving 400–500 t/day of waste) in Hue, Thua Thien Hue Province in central Vietnam; and the Luong Hoa landfill site (operating from 2014, landfill area 12.8 ha, receiving 480–500 t/day of waste) in Nha Trang, Khanh Hoa Province in southern Vietnam. We conducted the measurement surveys at these sites on, respectively, August 4 and 5, 2023 (Table 1). During the surveys, the weather in Hue was cloudy and the weather in Nha Trang was sunny. The surveys were conducted under harsh, hot, humid conditions with daily peak temperatures above 35°C.

3.2 Measurement Materials

We used a portable spectral radiometer MS-730 (from Eko Instruments Co., Ltd., Japan), which could measure spectral radiance and irradiance in a wavelength range from 350 nm to 1050 nm with intervals of 0.35 nm and calculate spectral reflectance. The spectral radiometer was mounted on a tripod, the sensor was oriented straight downward, and a 25° aperture attachment was mounted to measure the spectral radiance. Just before each subject was measured, a 30-cm square reflector with a reflectance of approximately 99%, SG3130 (from SphereOptics GmbH, Germany), was placed on the ground and its spectral irradiance was measured to calculate the spectral reflectance.

3.3 Measurement Methods

Figure 1 shows measurement points at the Thuy Phuong landfill site in Hue and the Luong Hoa landfill site in Nha Trang. The spectral radiometer was set up at a height of about 70 cm from the ground surface and measured the spectral radiance and irradiance of waste, soil, vegetation and leachate in a field of about 30 cm across directly below the sensor. This procedure was conducted three times at each measurement point. The measurements of waste were conducted at two different points at each landfill site. In addition to the sensor of the spectral radiometer being set up to measure waste from a height of about 70 cm, the sensor of the spectral radiometer was set up at a height of about 150 cm and measured waste in a field of about 70 cm across. Identification codes in the form of "Waste_w_x_y_z" were assigned to the spectral reflectance data for waste, where w was the landfill site location (H for Hue or N for Nha Trang), x was the waste measurement point within that landfill sites (A or B), y was the field of measurement (30 cm across or 70 cm across), and z was the ordinal designation of the measurement (1, 2 or 3). Identification codes were also assigned to the spectral reflectance measurement data for soil, vegetation and leachate in the forms of "Soil_w_y_z," "Vegetation_w_y_z" and "Leachate_w_y_z."

3.4 Data Analysis

The data measured by the portable spectral radiometer were immediately uploaded to a smartphone and stored as CSV files by the app "niji." Because data measured under substantially similar light intensities were useful, we compared the data with the spectral irradiance of the reflector that was measured just before the corresponding measurement and excluded from analysis

Table 1 Conditions at landfill sites in Hue and Nha Trang when measurements taken.

	Thuy Phoung landfill site	Luong Hoa landfill site
Landfill site location	Hue, Thua Thien Hue Province	Nha Trang, Khanh Hoa Province
Measurement date & time	August 4, 2023, 9:23–12:19	August 5, 2023, 10:53–13:23
Weather on measurement day	Cloudy	Clear
Peak temperature on measurement day	35ºC	36ºC

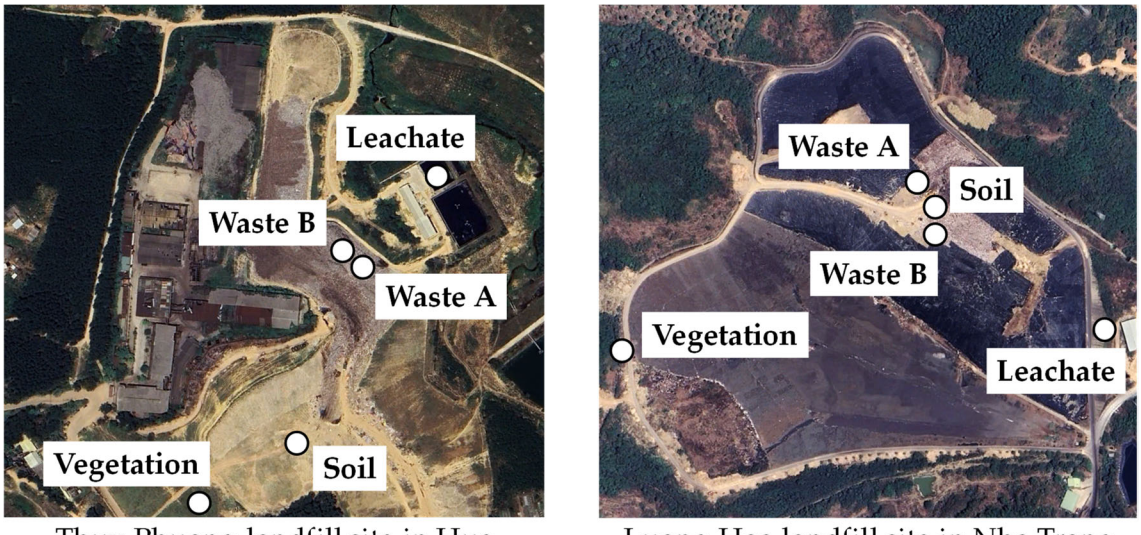

Fig. 1 Location for measuring spectral radiance and irradiance of waste, soil, vegetation and leachate with a portable spectral radiometer.

any data showing large divergences (more than approximately 0.01 W/m^2/nm). The following measurements were excluded, specifically as unstable measurement results under cloudy conditions at the Thuy Phuong landfill site in Hue: Waste_H_A_30_1, Waste_H_A_70_3, Waste_H_B_30_1, Waste_H_B_70_1, Soil_H_30_2, Leachate_H_30_3, Soil_N_30_2 and Vegetation_N_30_1. The spectral reflectance of each subject from 350 nm to 850 nm wavelength (at 0.35 nm intervals) was calculated from the measured spectral radiances and irradiances and plotted in figures. We then compared these spectral reflectance curves.

4. Results and Discussion

4.1 Spectral Reflectance Curves of Waste

Figures 2 and 3 show the spectral reflectance curves (in the wavelength range from 350 to 850 nm) of waste at, respectively, point A and point B of the Thuy Phuong landfill site in Hue. Figures 4 and 5 show the spectral reflectance curves (in the wavelength range from 350 to 850 nm) of waste at, respectively, point A and point B of the Luong Hoa landfill site in Nha Trang. At point B of the Luong Hoa landfill site in Nha Trang, the spectral reflectance curve of the waste when the field of measurement was 70 cm across showed a slightly different trend from when the field of measurement was 30 cm across, with a rise in the spectral reflectance appearing at around 400 nm. Otherwise, the spectral reflectance curves of waste exhibited regularity regardless of the measurement conditions. Even at different landfill sites and different measurement points, the spectral reflectance rose gradually by between 10% and 40% as the wavelength increased through the wavelength range from 350 nm to 850 nm. In all of the measurements, errors in spectral reflectance were less than about 10% between 450 nm and 750 nm and there were no large differences. This result indicates that waste, though generally heterogeneous, has a certain regularity in its spectral reflection characteristics. This new finding suggests that waste can be classified with other items in satellite data.

4.2 Comparison of Spectral Reflectance Curves of Waste with the Curves of Other Measurement Subjects

Figures 6 and 7 show the spectral reflectance curves (in the wavelength range from 350 to 850 nm) of waste at point A, waste at point B, soil, and vegetation and leachate at the Thuy Phuong landfill site in Hue and the Luong Hoa landfill site in Nha Trang. The measurement conditions were the same in all cases, with every field of measurement being 30 cm across. The spectral reflectance curves of vegetation and leachate (water) accurately reflected their features and showed obvious differences from the reflectance curves of waste and soil. There was

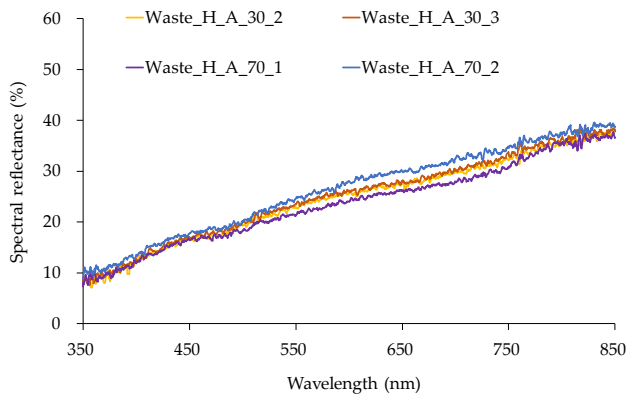

Fig. 2 Spectral reflectance curves of waste at point A of the Thuy Phuong landfill site in Hue.

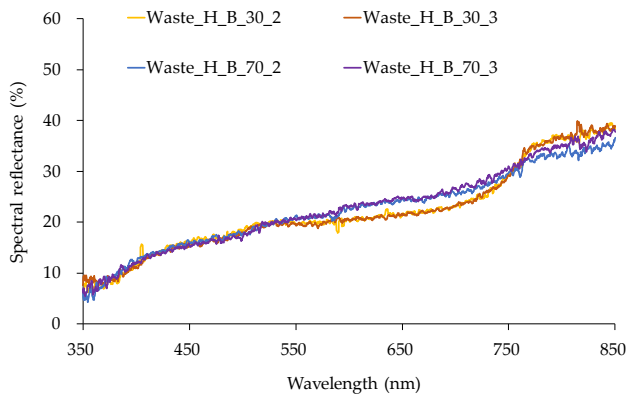

Fig. 3 Spectral reflectance curves of waste at point B of the Thuy Phuong landfill site in Hue.

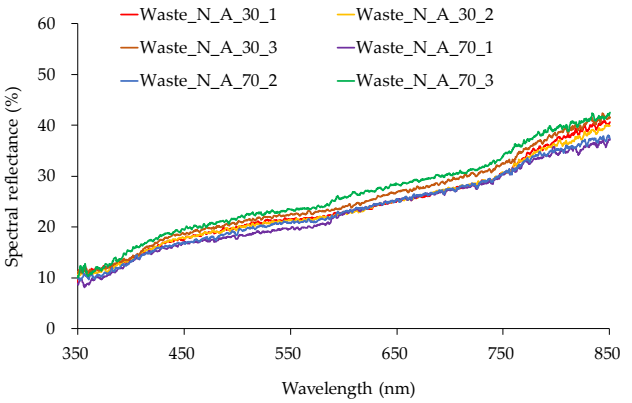

Fig. 4 Spectral reflectance curves of waste at point A of the Luong Hoa landfill site in Nha Trang.

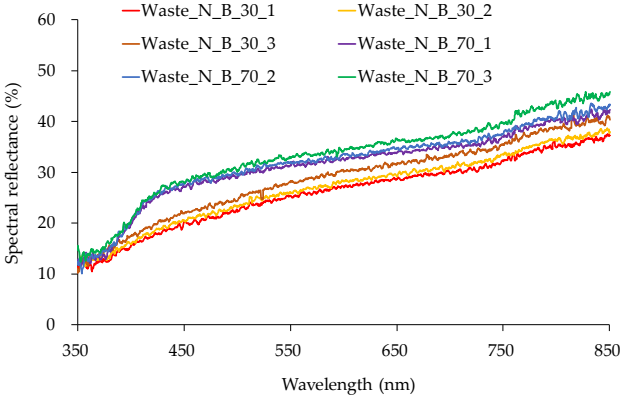

Fig. 5 Spectral reflectance curves of waste at point B of the Luong Hoa landfill site in Nha Trang.

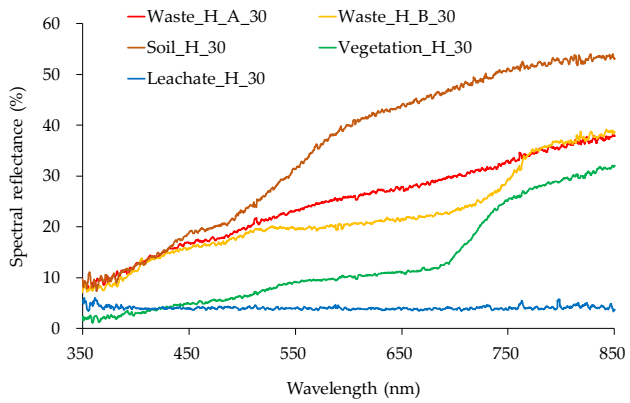

Fig. 6 Spectral reflectance curves of waste, soil, vegetation and leachate at the Thuy Phuong landfill site in Hue.

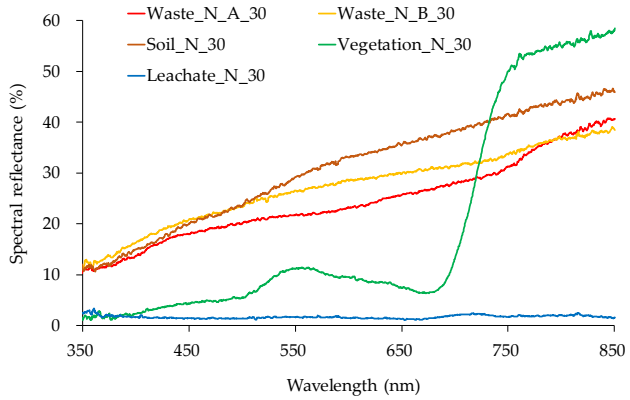

Fig. 7 Spectral reflectance curves of waste, soil, vegetation and leachate at the Luong Hoa landfill site in Nha Trang.

very little thriving green vegetation within the boundaries of the Thuy Phuong landfill site in Hue; the vegetation measurements had a brownish tinge. Consequently, the spectral reflectance curve was much lower in the wavelength range above 700 nm than the reflectance curve of vegetation at the Luong Hoa landfill site in Nha Trang.

The spectral reflectance curves of waste and soil differed from the spectral reflectance curves of vegetation and water. Even though soil had higher values of spectral reflectance than waste from around 500 nm, it can be seen that the spectral reflectance curves of soil were relatively close to the spectral reflectance curves of waste. Regardless of the landfill site and measurement point, very little difference could be seen between the spectral reflectance curves of waste, but the spectral reflectance curves of soil varied due to differences between the measurement sites. While there may be differences due to type and moisture content of soil, the spectral reflectance curves of waste were basically similar to the spectral reflectance curves of soil, and that was a new finding. We clarified the extent to which the reflective properties of waste differed from those of soil, vegetation and leachate at Vietnamese landfill sites. Although the spectral reflectance curves of waste were similar to those of soil, the result that the spectral reflectance curves of waste differed significantly from those of vegetation and leachate would be useful when selecting a method for analyzing satellite data.

5. Conclusions

In this study we conducted measurements of waste, soil, vegetation and leachate at the Thuy Phuong landfill site in Hue and the Luong Hoa landfill site in Nha Trang, Vietnam, using a spectral radiometer to acquire spectral reflectance curves of waste for use as basic data for the purpose of using satellite data to acquire information on locations of open dumping sites in developing countries. We confirmed from the results of the measurements that the spectral reflectance curves of waste had consistent regularity regardless of measurement point and field of measurement. These results suggest that using satellite data to develop techniques for identifying locations of open dumping sites will be worthwhile and signify that spectral reflectance curves of waste obtained by on-site measurements will be useful as ground-truth data.

We clarified that the spectral reflectance curves of waste differing significantly from those of vegetation and leachate would be useful when selecting a method for analyzing satellite data. Since the spectral reflectance curves of waste and soil are similar, the next research step will be to classify waste and soil based on factors other than spectral reflectance.More data must be accumulated from many more landfill sites, making use of the on-site-survey knowhow that we refined in this study to measure spectral radiance and irradiance of waste.

Acknowledgments

We are sincerely grateful to Hue Urban Environment and Public Works Company and Nha Trang Urban Environment Company for permitting our measurements at their landfill sites. We also profoundly appreciate the assistance of Pham Khac Lieu and Hoang Cong Tin of Hue University, Hideki Wada, Norihisa Hirata and Nguyen Huong Giang of Vietnam Waste Planning Co., Ltd., and Yukihiro Nakatani of Kankyo Techno Co., Ltd.

References

Alexakis, D.D. and Sarris, A. (2014) Integrated GIS and remote sensing analysis for landfill sitting in Western Crete, Greece. *Environmental Earth Sciences*, 72: 467–482. https://doi.org/10.1007/s12665-013-2966-y

Ishizaki, T., Shimaoka. T., Nakayama. H., Komiya. T. and Manabe, K. (2004) Satellite remote sensing for large-scale landfill management. *Environmental Systems Research*, 32: 311–318. (in Japanese)

Karakuş, C.B., Demiroğlu, D., Çoban, A. and Ulutaş, A. (2020) Evaluation of GIS-based multi-criteria decision-making methods for sanitary landfill site selection: the case of Sivas city, Turkey. *Journal of Material Cycles and Waste Management*, 22: 254–272. https://doi.org/10.1007/s10163-019-00935-0

Kawai, K. and Tasaki, T. (2016) Revisiting estimates of municipal

solid waste generation per capita and their reliability. *Journal of Material Cycles and Waste Management*, 18: 1–13. https://doi.org/10.1007/s10163-015-0355-1

Kaza, S., Yao, L.C., Bhada-Tata, P. and Van Woerden, F (2018) What a Waste 2.0: A global snapshot of solid waste management to 2050. Urban Development. Washington, DC. World Bank. http://hdl.handle.net/10986/30317 (accesed 23 June 2024)

Komiya, T., Ishizaki, T., Nakayama, H. and Shimaoka, T. (2006) Applicability of NDVI estimate of stabilization of large-scale landfill. *Environmental Systems Research*, 34: 423–431. (in Japanese)

Kosako, A., Miyazaki, S., Inoue, U., Tasaki, T., Osako, M. and Tamura, M. (2009) Detection of illegal dumping sites by using vegetation index and land surface feature from high resolution satellite images. *Journal of the Remote Sensing Society of Japan*, 29: 497–514. (in Japanese) https://doi.org/10.11440/rssj.29.497

Kruse, C., Boyda, E., Chen, S., Karra, K., Bou-Nahra, T., Hammer, D., Mathis, J., Maddalene, T., Jambeck, J. and Laurier, F. (2023) Satellite monitoring of terrestrial plastic waste. *PLoS ONE*, 18: e0278997. https://doi.org/10.1371/journal.pone.0278997

Nguyen, T.D.T., Kawai, K. and Nakakubo, T. (2021) Drivers and constraints of waste-to-energy incineration for sustainable municipal solid waste management in developing countries. *Journal of Material Cycles and Waste Management*, 23: 1688–1697. https://doi.org/10.1007/s10163-021-01227-2

Papale, L.G., Guerrisi, G., De Santis D., Schiavon, G. and Del Frate, F. (2023) Satellite data potentialities in solid waste landfill monitoring: Review and case studies. *Sensors*, 23: 3917. https://doi.org/10.3390/s23083917

Paul, K., Dutta, A. and Krishna, A.P. (2014) A comprehensive study on landfill site selection for Kolkata City, India. *Journal of the Air & Waste Management Association*, 64: 846–861. https://doi.org/10.1080/10962247.2014.896834

Saatsaz, M., Monsef, I., Rahmani, M. and Ghods, A. (2018) Site suitability evaluation of an old operating landfill using AHP and GIS techniques and integrated hydrogeological and geophysical surveys. *Environmental Monitoring and Assessment*, 190: 144. https://doi.org/10.1007/s10661-018-6505-x

Sadhasivam, N., Mohideen, A.R.S. and Alankar, B. (2020) Optimisation of landfill sites for solid waste disposal in Thiruverumbur taluk of Tiruchirappalli district, India. *Environmental Earth Sciences*, 79: 522. https://doi.org/10.1007/s12665-020-09264-0

Singh, S.K., Chokhandre, P., Salve, P.S. and Rajak, R. (2021) Open dumping site and health risks to proximate communities in Mumbai, India: A cross-sectional case-comparison study. *Clinical Epidemiology and Global Health*, 9: 34–40. https://doi.org/10.1016/j.cegh.2020.06.008

Trinh, L.H., Zablotskii, V.R. Vu, D.T., Zenkov, I.V. and Tong, T.H. (2021) Mapping and assessing landfills surface temperature using landsat 8 satellite data. A case study in Vietnam. *Izvestiya, Atmospheric and Oceanic Physics*, 57: 1098–1107. https://doi.org/10.1134/S0001433821090632

Yonezawa, C. (2009) Possibility of monitoring of waste disposal site using satellite imagery. *Journal of Integrated Field Science*, 6: 23–28.

Kosuke KAWAI

Kosuke Kawai is a senior researcher in the Material Cycles and Social Systems Research Section, Material Cycles Division, National Institute for Environmental Studies, Japan. During his Ph.D. studies at the Graduate School of Global Environmental Studies, Kyoto University, he started researching waste management in developing countries while staying at the Vietnamese Academy of Science and Technology. Recently, focusing on future changes in the quantity and quality of municipal solid waste, he has been engaged in research to design and analyze waste management scenarios for areas facing depopulation and aging in Japan, for example, by projecting the future amount of used disposable diapers generated. He is also developing new indicators for waste management and recycling toward decarbonization and a circular economy.

Ryoji KAWATA

Ryoji Kawata is a researcher at the Engineering Office for Remote Sensing, Kankyo Techno Co., Ltd. He has been conducting remote sensing research using artificial satellites and unmanned aerial vehicles. In recent years, he has been engaged in research using satellite data to identify heretofore unrevealed locations of inappropriate open dumping sites in developing countries, and he often visits such sites to measure the spectral reflectance of the waste on the ground. He is also actively engaged in remote sensing research in the fields of forestry and agricultural, applying remote sensing technology to identify the distribution and disease status of forests and the growth status of crops.

(Received 14 November 2023, Accepted 23 June 2024)