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Landfill Identification Through High-Resolution Satellite Images and Verification Using Drone Full Motion Video (FMV)

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In year 2020, a total of 2.9 million tonnes of solid waste was generated by Malaysians. The enormous solid waste generated will prompt irresponsible parties disposing it in illegal landfill by ignoring the guidelines had been set by the authorities. To prevent these illegal activities from being identified, the landfill is usually located in hidden areas hence difficult to detect using conventional methods. Indeed, it is a serious matter that must be borne by the government because of its negative impact on human health and the environment. Using the latest advances in remote sensing technology, the location of landfills can be identified through high-resolution satellite images and verified using drone systems with Full Motion Video (FMV) to provide accurate information to local authorities for enforcement. Therefore, Malaysian Space Agency (MYSA) in an effort to develop a new technique to assist the authorities in the waste category verification, landfill area size estimation and identifying the nearest sensitive area affected. In this paper, a pilot test conducted in Klang Valley area in years 2019 to prove the remote sensing technology is able to make the local authority's enforcement work more effectively and the dynamic information data acquisition is useful for prosecution evidence in court

Keywords: Landfill; Remote Sensing; Dumping Site; High-Resolution Satellite Images; Drone Full Motion Video (FMV); Visual Analytics

I. INTRODUCTION

According to Department of Statistics Malaysia, a total of 2.9 million tonnes of solid wastes was produced in 2020 by states that adopted the Solid Waste and Public Cleansing Management Act 2007 (Department of Statistics Malaysia, 2021). Solid waste consists of waste generated from household, commercial and institutional (CI) and industrial (Jereme *et. al.,* 2015; KPKT, 2015; Rahim *et al.,* 2017). Globally, the rate of illegal landfill has been an issue of concerns by governments, of which a number of sites were linked to industrial waste found in remote areas (Triassi, M *et. al.*, 2015; APHRC, 2017; Tiseo, L, 2021; MDEQ). In the state of Selangor alone, there are 500 illegal plastic waste facilities operating without approved permit from the National Solid Waste Management Department whereby most of the plastic waste were not processed correctly instead they were dumped or burnt in open air (Greenpeace Malaysia, 2018). Such activities can cause adverse of both short and long-term effects on health and the environment (Porta, D *et. al.*, 2009; Mattiello, A *et al.*, 2013). The illegal waste burning has contributed significantly to the increase in environmental pollution, particularly of dioxins. General symptoms such as stress, anxiety, headache, dizziness, nausea, eye and respiratory irritation have been also described (Kah, M *et al.*, 2012).

In addition, construction and demolition (C&D) solid waste is also one of the materials that are illegally disposed. The projection of C&D solid waste generated in 2020 is about 36,473 tons per day. According to statistics as shown in Figure 1, 60% of C&D waste were possibly dumped illegally at private land (KPKT, 2015). The illegal dump of C&D waste

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can cause threat to human life where it contributes to the growth of mosquitos breeding ground in which leads to dengue fever.

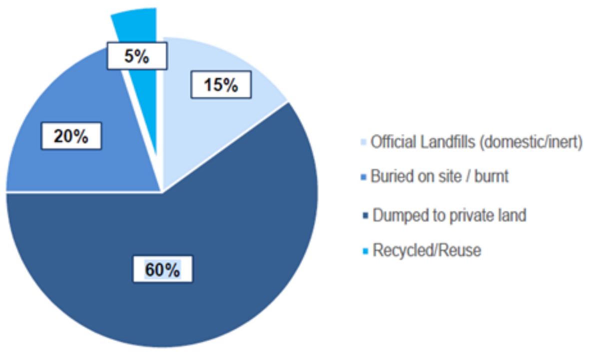

Figure 1. Disposal of C&D Solid Waste (KPKT, 2015)

Remote sensing technologies are considered as one of the alternatives in detecting waste disposal activities. Several researches have been done over the past 15 years in developing methods on monitoring and mapping hotspot waste disposal area using remote sensing technologies which include satellite images, airborne data and most recently the use of unmanned aircraft system (UAS) or also known as drone. For identification of waste disposal area, high-resolution satellite imagery is required to identified small area of disposal sites such as illegal domestic waste disposal sites. Visual identification technique is used in several existing methods appears to be relatively effective however, it requires significant time and human expertise (Glanville, 2015).

The use of drone is also being applied in waste management for real-time landfilled monitoring because it is safer and cheaper compared to monitoring and inspection using the conventional method or manned aircraft. It is because sometimes dangerous situation, potential threat or restriction by irresponsible individual occurred and reported when ground monitoring and inspection on the hotspots area are implemented (Greenpeace Malaysia, 2018). In Australia, drone is used to tackle and deter illegal landfill site especially in remote area by which the recorded video will be used as evidence to prosecute offenders. Furthermore, the effectiveness in using drone to collect and record video evidence had been successfully exhibited by Environment Protection Authority Victoria which issued 98 remedial notices to stop or clean up illegally dumped waste across the state (Waste Management Review, 2016). Thus, information can be quickly identified through the combination of remote sensing satellite and drone data especially of those areas beyond or difficult-to-reach and dangerous.

In this study, FMV technologies were implemented for identification and verification in real-time where the FMV data is a digital video data that embedded with spatial information and fully compatible to be exploited in standard geographic information system environments (Sharom *et al.*, 2021a). By using the FMV data, waste category verification and estimated area of waste disposal sites can be assessed in real-time. In Section 2, explanation on the usage of high-resolution satellite imagery for identifying potential landfill site is presented. Section 3 discusses the process of identification of hotspots through the use of high-resolution satellite images and drone technology to gather real-time information FMV data. The pilot test and results are reviewed in Section 4 while in Section 5, the conclusion of this study is drawn. This study aims to identify and verify the location of landfills using the latest advances in remote sensing technology in order to provide accurate information to local authorities for enforcement purpose.

II. POTENTIAL LANDFILL SITE IDENTIFICATION USING HIGH-RESOLUTION SATELLITE IMAGES

The pilot test was conducted in Klang Valley area, the west of Peninsular Malaysia. The Pleiades and SPOT-7 satellite images data with resolution range 0.5 to 1.5 meter were used in this study. The observation dates were 14 February 2019 for SPOT-7, whereas 22 February 2019 and 26 March 2019 for Pleiades data. Pan-sharpened images of the target area generated from the data and then targets in the obtained images were identified accordingly. There are many methods had been developed for identification of dumping site using satellite images based on resolution and type of sensor as presented in Table 1 below.

Table 1. The identification methods of landfill site areas using several categories of satellite images

Sensor Used	Resolution (meter pixel size)	Methods of Analysis
Moderate Resolution Satellite Data	12–50	Combination of principal component transformation and unsupervised classification
Medium Resolution Satellite Data	4–12	Spectral signatures and pure spectral pixels
High to Very-High Resolution Satellite Data	high (1–4) and very-high (0.5–1)	Visual identification techniques

For this study, high-resolution data was used for visual identification and analysis. Pan-sharpened high-resolution imagery is very helpful to extracting surface changes by visual interpretation depends on how radiance differs which is affected by transmittance and solar zenith angle. Furthermore, in the visible images, dumps are simply identified since they are noticeable compared to the background of ambient environment as well as having textural characteristics (Richter, 2019). Thus, from these images any scrap or junk were easily identified since plastic, concrete and bare soils generally appeared as high reflectance and inhomogeneous structure. The use of Pleiades and SPOT-7 which provide high-resolution images were able to detect dumping site which is surrounded by build-up and vegetation area by assuming the presence of garbage and its distance from residential area.

Based on previous study, the use of multispectral remote sensing data and digital image processing revealed that it is possible to map solid waste landfills and vegetation stress which could be indirect indicators of liquid and gaseous waste leaks (Ottavianelli *et al.*, 2005). Therefore, in visual interpretation technique the target area was identified and evaluated using risk level criteria as follow:

i. Unoccupied Area;
ii. Sick/Dead Vegetation;
iii. Route In/Out;
iv. Soil or Water Texture/Colour;
v. Isolated from Residential Area;
vi. Near to Drainage System; and
vii. Waste Deposit.

Unoccupied area and waste deposit are indicated by an open area with brownish white colour as well as having uneven texture, this texture usually looks smooth. Typically, a healthy normal vegetation will appear green in satellite image, in contrast a sick/dead vegetation will be brownish in colour. Route in/out can be seen clearly in a high-resolution image with some features like road network constructed of gravels and tar or red soil forming a line. Water appears dark blue in colour with uniform and flat surface texture. Some of the potential dumping site areas might be far away from residential area where the routes are distant from any main road. In addition, by using the criteria that provided by the vector data, the location nearby to drainage system is one of the potential disposal locations that have been identified.

The Malaysian Technical Guideline categorises landfills into four levels. The summary of the classification of the level and the proposed facilities are shown in Table 2. Below are the general descriptions of landfill according to levels:

- Level 1 - Controlled tipping
- Level 2 - Sanitary landfill with a bund and daily cover
- Level 3 - Sanitary landfill with leachate recirculation system
- Level 4 - Sanitary landfill with leachate treatment facilities

Table 2. Levels of sanitary landfills (MHLG, 2006)

Facilities	Level 1	Level 2	Level 3	Level 4
Soil Cover	*	**	**	**
Embankment		**	**	**
Drainage Facility		**	**	**
Gas Venting		**	**	**
Leachate Collection			**	**
Leachate Recirculation			**	**
Leachate Treatment				**
Liners				**

* to be provided periodically
** to be provided daily

From the criteria and parameter used in this visual identification technique, 10 potential dumping sites randomly selected for further verification process using FMV drone system to gather accurate information at the hotspot areas.

III. THE REAL-TIME LANDFILL SITE DETAIL AND VERIFICATION USING DRONE FMV DATA

Based on the potential dumping site hotspot identified through high-resolution satellite images, MYSA together with related agencies have utilised drone to acquire dynamic information for verification and examination of the disposal areas. This information is an essential input for effective enforcement works because it can increase the authority's ability to identified landfill site that ignoring the guidelines had been set by the authorities in remote and difficult-to-reach locations, as well as to provide evidence to prosecute offenders.

FLIR SkyRanger R60 (SkyRanger) drone system was used to acquire real-time information at the identified dumping site. SkyRanger system is equipped with optical sensor that is capable to acquire FMV data. The acquired FMV data was streamed in 1080p resolution directly from drone to the ground station at the drone operation site for real-time FMV data analysis using TacitView software. The real-time FMV data that had been streamed to the drone operation site was also streamed to MYSA Operation Command Centre (OCC) in Kuala Lumpur by using Dejero devices for decision making purpose by the authorities.

Dejero devices transmit high-quality live video with low latency by using integrated smart blending technology intelligently that combines multiple network connections in real-time for enhanced reliability, expanded coverage and greater bandwidth capacity. In this study, the drone was operated 100 meter above ground level (AGL) altitude and within visual line of sight (VLOS) radius.

High-resolution optical satellite images at the potential hotspot area were uploaded and displayed into TacitView software to ensure the verification tasking can be done at the right location. Figure 2 below shows the interface of TacitView Software used by the drone data analyst to analyse the hotspot areas.

Figure 2. TacitView Software Interface

The use of drone is important to verify dumping areas that are inaccessible or difficult-to-reach by the enforcement agencies. The land with minimum visibility/private land/difficult-to-reach and dangerous area tends to be an attractive place for illegal dumping site (Waste Management Review, 2016). During drone verification task the following information can be potentially obtained:

i. The waste category;
ii. The estimation area of dumping sites;
iii. The sensitive area (e.g., Residential, School and Waterbody); and
iv. The evidence in the form of picture/video of irresponsible individual/activities such as identity of the suspects, vehicle registration number and potential threat to the local authority to enter the area.

Figure 3 and Figure 4 exhibit examples of the output from Call Out method analysis made during in-flight in potential hotspot area where the same method has been implemented by MYSA to extract real-time information in flood designated hotspot area (Sharom *et al.*, 2021b). This method easily measures the area of dumping sites in real-time while information is disseminated through live streaming to MYSA OCC, Kuala Lumpur.

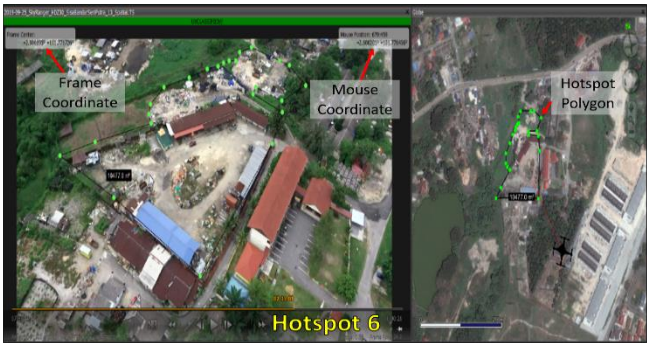

Figure 3. In-flight Call Out method to estimate the hotspot area size and hotspot coordinate

Figure 4. The seepage of polluted water from hotspot area streamed into nearby waterbody

The drone FMV data exploitation by using Super-Resolve method has the capability to increase the resolution Area of Interest (AOI) for the identification of waste category, irresponsible individual/suspects and vehicle/machine registration number in the dumping site area. The Super-Resolve method extracted single frame image from the FMV data by using high quality spatial (in-frame) upscaling and motion compensation for finding corresponding areas in neighbour frames algorithms. Next, the video motion detection and tracking were then employed using sub-pixel accurate motion compensation within the similar areas in neighbour frames and intelligently merged frames to combine information to enhance the identification capability. Figure 5 and Figure 6 show examples of super-resolve image extracted from drone FMV with enhanced identification capability.

Figure 5. The identification process of vehicle registration number operated in the hotspot area

Figure 6. Several waste categories in the dumping site area

IV. PILOT TEST AND RESULT

As a result of methods used and explained in Section 2, the pilot test had been able to identify hotspot locations through high-resolution satellite images. Of the 10 randomly selected locations—several hotspots had been identified. All the identified potential hotspots demonstrate criteria such as unoccupied area, sick/dead vegetation, route in/out, soil and water texture/colour clearly visible using the high-resolution satellite images. Therefore, the verification through drone system deployment as described in Section 3 was executed after the extraction of hotspots location were provided. The real-time FMV drone data were then broadcasted from the operation site to OCC for verification process by which during this time an officer from MYSA Environment Task Force team categorised the types of solid waste. This solid waste classification had been clearly verified through visual interpretation by zooming-in into dumping site area using drone optical sensor which is capable to zoom up to 30x optical zoom. Then the resolution on the selected AOI of the dumping site was enhanced by using the Super-Resolve method to obtain more detailed information and texture of the waste. The classification for every type of waste was made based on developing integrated solid waste management plan training manual published by United Nations Environment Programme (UNEP, 2009). The FMV drone footage and information of the potential hotspots are as presented in Figure 7–11.

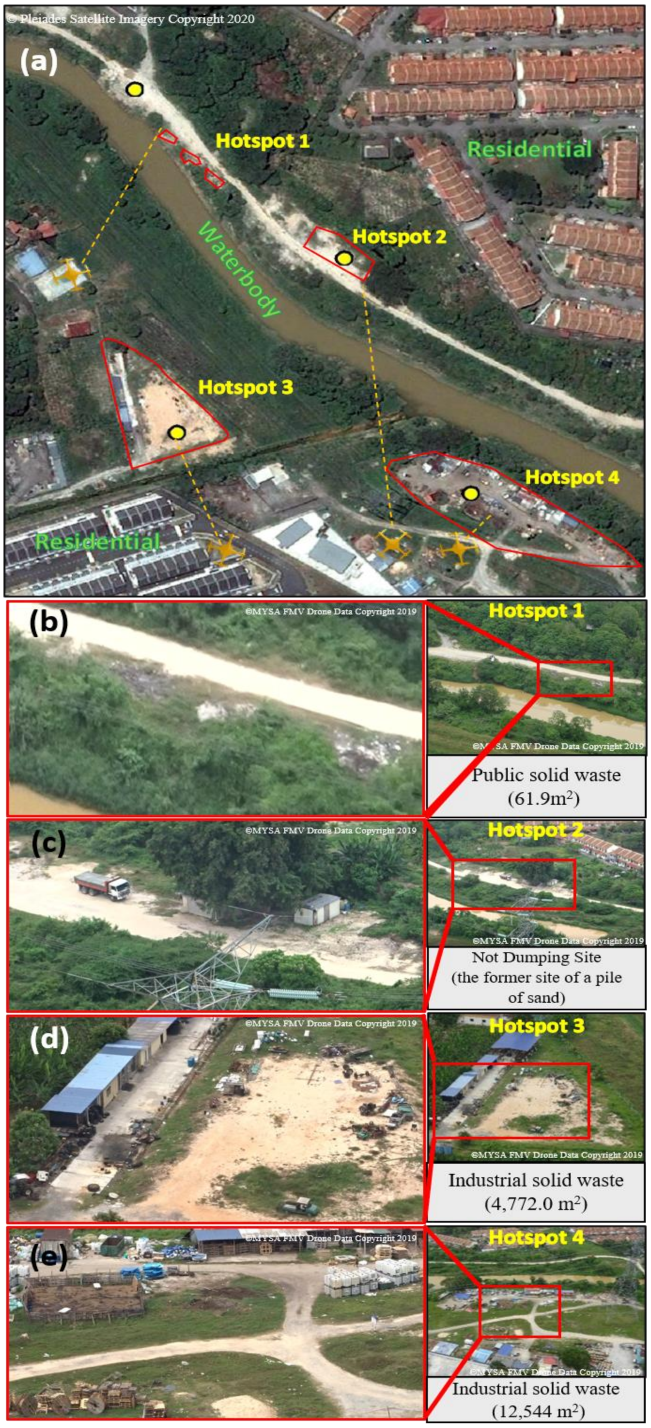

Figure 7. (a) Pleiades satellite image of Hotspot 1-4, (b) Drone Zoom-in at Hotspot 1, (c) Drone Zoom-in at Hotspot 2, (d) Drone Zoom-in at Hotspot 3, and (e) Drone Zoom-in at Hotspot 4

Figure 7(a) illustrates 4 selected hotspots (marked as Hotspot 1, Hotspot 2, Hotspot 3 and Hotspot 4) which were identified from Pleiades satellite image. To verify the selected hotspot, drone system was deployed and based on the verification, it shows that only hotspot 1, 3 and 4 are the dumping site areas. Meanwhile, Hotspot 2 is only a remnant of a former site with a pile of sand. The type of waste can be verified when the drone system zoomed at the dumping site area. The zooming-in at hotspot 1 shows burnt effects that is located near a residential area which presumably used to burn public solid waste. Images in hotspot 3 and 4, indicate these two areas were used to dump industrial waste such as vehicles parts, wood and plastic products, respectively.

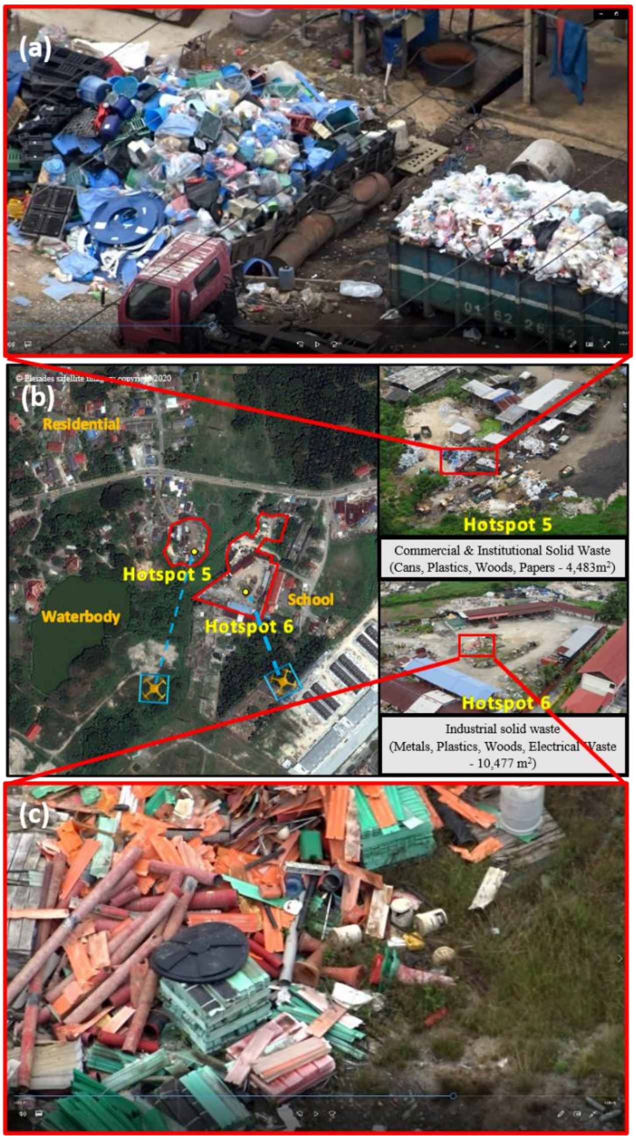

Figure 8. (a) Drone Zoom-in at Hotspot 5, (b) Pleiades satellite image of Hotspot 5 and 6, and (c) Drone Zoom-in at Hotspot 6

Figure 8(a) shows a Roll-On Roll-Off (RORO) bin with a full load of CI waste and also can be seen is a pile of recyclable plastic material such as PolyPropylene (PP) plastic stools, High-Density Polyethylene (HDPE) plastic pallets and industrial stackable basket. The FMV data also recorded a manually waste separation process and several solid waste piles were separated accordingly by material categories. Verification results found the several piles of solid waste such as food cans, wooden pallets, electrical cable drums, paper boxes and industrial packaging plastic bags were placed in open areas and did not follow the guidelines set by the authorities. The images in Figure 8(b) shows that hotspot 5 and 6 are areas that perform solid waste recycling activities.. The location of hotspot 5 is in a restricted area situated in the midst of pylon cable reserve land while hotspot 6 is located in a full fenced private land next to a primary school area without any buffer zone placed within the two premises. These two hotspots had no leachate collection and treatment and appeared to channel leachate directly to a nearby waterbody through a ditch. Figure 8(c) shows the FMV Drone footage with 30x optical zoom effortless capability in identifying the type of waste in hotspot 6. Some industrial solid waste scattered in this hotspot were HDPE corrugated cable pipes, PolyVzcinyl Chloride (PVC) safety plastic cone, plastic road barrier, cable drum with black electric cable and others. Obviously, scattered solid waste dumped in the open area are ideal habitat for dengue larvae which exposes definite health risks to the public especially the students from nearby schools.

Figure 9. (a) Pleiades satellite image of Hotspot 7, and (b) Drone Zoom-in at Hotspot 7

Figure 9 shows an abandoned pond under the electricity pylon reserved land was used as a household solid waste dumping site. A lot of bottles, polystyrene boxes and other plastics were found littered into the pond. The pond water turned dark colour pinpointed that the water had been polluted. Nearby the pond area, a noticeable pile of special waste category was present, the waste which were large and hard-to-handle items such as furniture and branches.

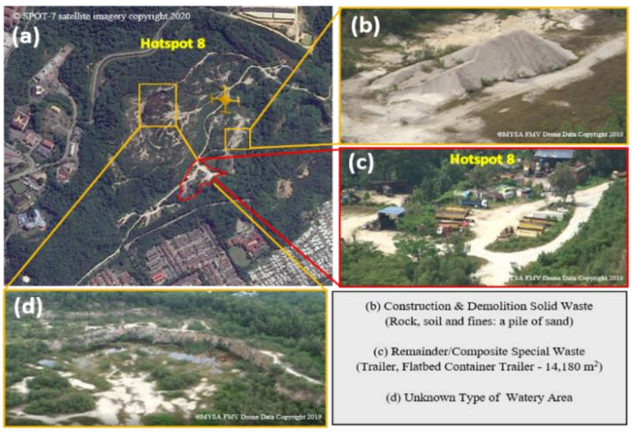

Figure 10. (a) Spot-7 satellite image of Hotspot 8, (b) Drone Zoom-in at C&D Solid Waste Dumpsite, (c) Drone Zoom-in at Hotspot 8, and (d) Drone Zoom-in at Unknown Category

In Figure 10(a), hotspot 8 was identified from Spot-7 satellite image. Hotspot 8 is located in a hilly forest area in the suburbs (remote area) with limited access (red soil route) to that area. The verification process conducted using the drone system denoted that the area was occupied by a lot of abandoned trailers and flatbed container trailers categorised under Remainder/Composite Special Waste category as shown in Figure 10(c). While, the observations around areas of hotspot 8 found that there were some clear lands with sand piles as shown in Figure 10(b). In Figure 10(d), watery areas were discovered however, the type of liquid could not be verified by the drone system. Although there was a trace of route-in and route-out to access that area, a ground truth verification as in the collection of liquid sampling is required to determine if it has been a spot for hazardous waste dumping site.

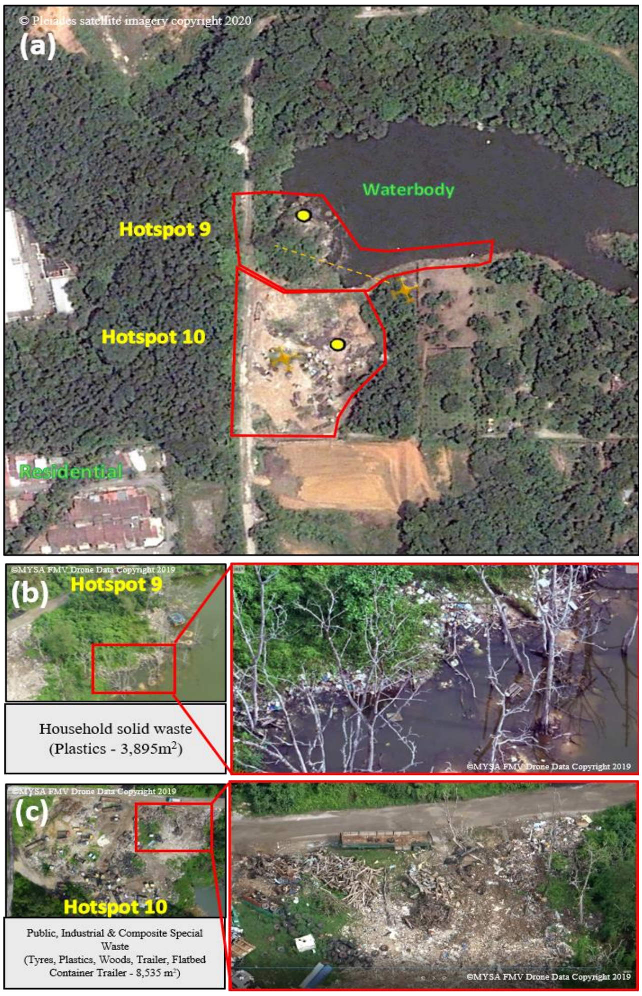

Figure 11. (a) Pleiades satellite image of Hotspot 9 and Hotspot 10, (b) Drone Zoom-in at Hotspot 9, and (c) Drone Zoom-in at Hotspot 10

Figure 11(a) illustrates hotspots 9 and 10 locations are at lake areas in suburbs forest (remote area) with route made from aggregate materials. Via satellite data, it can clearly be seen that a rapid development surrounded that area, as there are several new condominium constructions, commercial building and residential housing areas. Figure 11(b) shows hotspot 9 was identified as dumping site area for household waste. There were a lot of household waste such as plastic bags, plastic water bottles, empty paint cans and other waste dumped around the lakeside area. Besides being the major cause of dead trees in the surrounding area, the dumpsite is also affecting the parameter with its seepage flowing directly into the lake. The seepage water turned the lake water into a dark colour; a clear indication that the water had been contaminated. Meanwhile, some of the rubbish piles along the roadside showed signs of open burning which was used as one of the ways for waste disposing. Figure 11(c) reveals a large waste disposal area at hotspot 10 where there were various categories of waste disposed there. Among the waste verified were from the Special Waste category, such as flatbed trailers, obsolete heavy machinery and tires. The Public Solid Waste category that verified at the hotspot area were branches and trunks. There are also from piles of Reclaimed Asphalt Pavement (RAP) found along the roadside under C&D Solid Waste category. Furthermore, there are no existing proper drainage system to treat wastewater which otherwise directly discharged into the lake beside the dumpsite that causing vegetation sickness and death.

All the information such as type(s) of waste, size area of the hotspots and video of on-site activities were recorded for further action. However, the accuracy of waste size area measurement relies on the FMV data spatial accuracy which is based on the accuracy and precision of the aircraft/drone GNSS and drone's navigation system (latitude, longitude, altitude & etc.) where the SkyRanger drone system used GPS for flight controller and geotagging which have root mean square error in the radial direction ($RMSE_r$) GPS more than 3 meters (Kalacska *et al.,* 2020). Likewise, the orientation information of the camera also affects the accuracy of the FMV spatial data (Taylor & Settergren, 2012; Coffman, 2015; ESRI, 2018; Inside Unmanned Systems, 2020; Patel & Butler, 2020; Sharom *et al.*, 2021a). The 9 out of 10 hotspot areas are classified as dumping site as in Table 3.

Table 3. Results of Solid Waste Verification Process

No	Location	Type of Waste	Waste Area Size (m²)	Figure
1	Bangi (Hotspot 1)	Public Solid Waste	61.9	Figure 7
2	Bangi (Hotspot 2)	Not Dumping Site	-	
3	Bangi (Hotspot 3)	Industrial Solid Waste	4,772	
4	Bangi (Hotspot 4)	Industrial Solid Waste	12,544	
5	Bangi (Hotspot 5)	CI Solid Waste	4,483	Figure 8
6	Bangi (Hotspot 6)	Industrial Solid Waste	10,477	
7	Bangi (Hotspot 7)	Household Solid Waste	2,107	Figure 9
8	Selayang (Hotspot 8)	i. C&D Solid Waste; andii. Remainder/ Composite Special Waste	14,180	Figure 10
9	Rawang (Hotspot 9)	Household Solid Waste	3,895	Figure 11
10	Rawang (Hotspot 10)	i. Public Solid Waste; ii. Special Waste; and iii. C&D Solid Waste.	8,535	

V. CONCLUSION

In this study the dumping sites in hotspot areas were distinguished easily through the absence of several facilities such as site office, leachate treatment plant, proper drainage system and security control. It can be observed that the sites are characterised by the presence of scattered waste, absence of daily soil cover and located far away from the main road. The close distance between landfill and sensitive areas such as school, residential and waterbody pose environmental threats that directly contributed to health hazards on students and nearby communities. Electricity pylon reserve land and waterbody area have a higher potential to be an urban/suburbs dumping site hotspot.

Evidently, remote sensing technologies have the ability to trace dumping sites as well as serving as a new mechanism to enhance the related agencies capabilities in enforcement works. For further research, high-resolution satellite images and drone FMV have the potential in automated verification of dumping site by using deep learning algorithm.

VI. ACKNOWLEDGEMENTS

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