Public Policy Research Funding Scheme

公共政策研究資助計劃

Project Number :
項目編號： 2022.A6.191.22A

Project Title :
項目名稱： Developing Low-Cost Remote Sensing System for Detecting Illegal Dumping of Construction Waste in Hong Kong
利用低成本遙感系統監察香港非法傾倒建築廢料活動

Principal Investigator :
首席研究員： Dr ZHU Xiaolin
朱孝林博士

Institution/Think Tank :
院校 ／智庫： The Hong Kong Polytechnic University
香港理工大學

Project Duration (Month):
推行期 (月) ： 12

Funding (HK$) :
總金額 (HK$)： 281,060.00

Developing Low-Cost Remote Sensing System for Detecting Illegal Dumping of Construction Waste in Hong Kong

利用低成本遙感系統監察香港非法傾倒建築廢料活動

Final Report

Prepared by

Xiaolin ZHU, Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic

Hongsheng ZHANG, Department of Geography, The University of Hong Kong

Luoma WAN, Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University

Jing WANG, School of Biological Sciences, The University of Hong Kong

Jiaqi TIAN, Department of Geography, National University of Singapore

Date: August 9, 2023

Acknowledgement

This research project (Project Number: 2022.A6.191.22A) is funded by the Public Policy Research Funding Scheme of The Government of the Hong Kong Special Administrative Region.

Contents

Executive Summary

1) Abstract of the Research

Illegal dumping resulting from rapid urbanization is a global problem. In Hong Kong, more than 40,000 tons of Construction and Demolition (C&D) materials are generated daily by local industries. Illegal dumping may cause serious problems, such as land occupation, environmental issues, and hygiene problems. It has become the third-largest pollution complaint in Hong Kong. Due to the stealthy and arbitrary nature of illegal dumping, accurate detection of illegal dumping is still a challenge, especially on a large scale.

This research aims to develop a framework for illegal dumping detection based on high spatio-temporal resolution PlanetScope images. We first introduced an automatic cloud and shadow detection approach to accurately detect clouds and cloud shadows and reduce their effects on illegal dumping detection. Then, the bi-temporal changes were obtained among four adjacent valid observations using the Iteratively Reweighted multivariate alteration detection (IRMAD). Furthermore, we filtered the changes resulting from the illegal dumping of construction wastes by coding the bi-temporal changes based on the fact that the land cover changes from illegal dumping do not easily recover in a short period. We also introduced shape features to further remove the false alarms caused by the errors in image registration. Finally, the land use map was used to assist in the legality check for C&D dumping.

We tested the proposed framework in Hong Kong and detected approximately 51.93 ha of suspicious areas where illegal C&D dumping might happen in 2021, including vacant land/ construction in progress, agricultural land, and open storage. Nine out of nineteen C&D dumping activities the Hong Kong government acknowledged were also accurately detected, and the activities of C&D disposal in the rest sites had not started by the end of 2021. Besides, the dates of the dumping activities were also obtained. With this information, it could greatly assist the Hong Kong government in the management of illegal C&D dumping.

高速城市化導致的非法傾倒拆建廢料是個全球性問題。香港本地建造業每日產生超過 40,000 噸拆建廢料。非法傾倒拆建廢料會引致土地侵佔、環境污染及公共衛生等問題。在香港，非法傾倒拆建廢料已成爲第三大污染投訴來源。由於非法傾倒活動的隱蔽和隨意性，在大範圍內精確監測非法傾倒拆建廢料仍極具挑戰。

本研究旨在研發一套基於高時空分辨率 PlanetScope 影像監測非法傾倒拆建廢料框架。首先，我們採用雲及陰影自動檢測方法對 PlanetScope 影像進行雲和陰影檢測，以減少其對非法傾倒拆建廢料檢測的影響。其次，使用迭代加權多元變化檢測方法（IRMAD）在四幅相鄰的有效觀測影像之間進行雙時態變化檢測。非法傾倒拆建廢料會造成土地覆蓋變化，並在短時間內不會恢復。因此，我們對雙時態的變化檢測結果進行編碼，篩選出由非法傾倒拆建廢料造成的土地覆蓋變化，並引入變化區域的形狀特徵，以減少由於圖像配準錯誤造成的虛假變化。最後，利用土地利用地圖判斷偵測的傾倒拆建廢料活動是否合法。

我們在香港對研發的非法傾倒拆建廢料監測框架進行了檢驗。在 2021 年，我們在共約 51.93 公頃的區域監測到疑似非法傾倒拆建廢料活動，包括空置土地/在建工程、農地和露天倉庫等。根據 2021 年香港環境保護署公佈的擺放建築廢物通知書，我們共搜集了 19 個樣本對結果進行檢驗，其中 9 個地方監測到正進行的擺放活動，10 個地方監測到並未開始的擺放活動。此外，我們還獲取了擺放建築活動的日期。這些資料可以幫助香港政府有效管理非法傾倒拆建廢料活動。

2) Layman Summary on Policy Implications and Recommendations

The proposed framework aims to screen all suspected illegal dumping activities in Hong Kong using high-resolution satellite images and a decision system, thus assisting the Hong Kong government to effectively and efficiently manage illegal dumping of C&D. After processing 2096 image scenes with a total volume of 801GB data in 2021, this research has the following main findings.

Firstly, 3441 suspected illegal C&D dumping sites with an area of 51.93ha were detected, most of which are beyond the scope of existing black spots. This is the first time that the area of the affected sites is quantified, providing scientific evidence to tackle illegal dumping with more complementary measures.

Secondly, Yuen Long and North districts were the most affected areas, especially in the vacant land/construction in progress, agricultural land, open storage, grassland, and rural settlement areas. Therefore, the Hong Kong government should pay more attention to these land uses in the two districts.

Thirdly, in 2021, there were 190 days when illegal dumping was detected, and more areas with suspected illegal dumping were detected in the second half year. Nevertheless, year-round monitoring of illegal dumping of C&D is still needed.

Finally, the changes caused by the disposal of C&D at construction sites, such as land reclamation in Kei Tau Kok and building construction in Kai Tak, were also detected, indicating another function of proposed framework in monitoring the progress of construction.

Instead of screening illegal dumping of C&D, this framework only provided suspicious illegal dumping, given the precision and standardization of laws and the complexity of legality verification. In order to accurately identify illegal dumping and effectively support the management of illegal dumping, we also have the following policy recommendations.

Firstly, the Hong Kong government should promote the capacity of **overall monitoring** of illegal dumping of C&D with the latest technologies (i.e., remote sensing with high spatio-temporal resolution). Although existing measures, such as surveillance cameras installation at black spots, reports from public, etc., have significantly improved the situation in some local regions, they only focus on black spots and may lead to dumping transfer rather than dumping eradication if no overall monitoring is available.

Secondly, it is suggested to establish a performance evaluation mechanism for the management of illegal dumping. The Hong Kong government continues investing in new technology, i.e., surveillance cameras, for illegal dumping management, and new black spots are built every year. Still, we cannot find any comprehensive evaluation criteria for illegal dumping management. Without evaluation criteria, we cannot select the effective measures to eliminate illegal dumping. Therefore, a performance evaluation mechanism is urgent and necessary.

Thirdly, more relevant departments should collaborate to combat the illegal dumping, mainly including Lands Department, Civil Engineering and Development Department (CEDD), Agriculture, Fisheries and Conservation Department (AFCD), Environmental Protection Department (EPD), Food and Environmental Hygiene Department (FEHD), Planning Department. The transfer of dumping activities not only causes additional difficulties in detection, but also in legality review, as it crosses different land use and duty scopes. Besides,

the circulation of C&D disposal is a closed path with a source and a destination, involving different departments. Tracing the source and destination can contribute to the management of illegal dumping. Therefore, cooperation between more departments is needed.

本研究所研發的框架旨在利用高解析度遙感影像和決策系統檢測出香港所有疑似非法傾倒拆建廢料活動，支援香港政府有效、高效地管理非法傾倒拆建廢料活動。在處理 2021 年 2096 景總計 801GB 遙感影像數據，本研究有如下主要發現。

首先，在 3441 個地點總計 51.93 公頃區域檢測到疑似非法傾倒拆建廢料活動，大部分地點都不在現有黑點範圍內。這是首次量化了疑似非法傾倒拆建廢料活動的面積，為需要更多的補充手段用於監測非法傾倒拆建廢料活動提供了科學依據。

其次，北區和元朗是非法傾倒拆建廢料活動的主要區域，特別在空置土地/在建工程、農地、露天倉庫、草地以及鄉村等區域。因此，政府需要對以上兩區進行密切監測。

此外， 我們在 2021 年的 190 天中均偵測到疑似非法傾倒拆建廢料活動，且大部分非法傾倒拆建廢料活動集中在下半年。盡管如此，我們仍需要對非法傾倒拆建廢料活動進行全年監測。

最後，我們發現項目研發的框架不但可以檢測出非法傾倒拆建廢料的區域，而且可以檢測出在建工程的變化，如企頭角的填海區域、啓德區域的城市建設。因此，所研發的監測框架還可以用於進行工程進度監測。

鑒於法律的準確性和規範性以及傾倒活動合法性鑒別的複雜性，本項目並非準確檢測出非法傾倒拆建廢料活動，而是提供疑似非法傾倒拆建廢料活動區域。爲了更準確地識別出非法傾倒拆建廢料活動區域和更高效地支援管理，我們有如下政策建議。

首先，香港政府需要進一步引進最新技術，如遙感，提升**全面監測**非法傾倒拆建廢料活動的能力。雖然現有措施，包括在黑點建立視頻監控、公衆舉報等，已成功改善了局部區域非法傾倒拆建廢料活動的現象，但只限於黑點區域；如果沒有全面監測能力，

容易造成非法傾倒拆建廢料從黑點轉移到其他地點而不能從根本上對非法傾倒進行治理。

其次，建議建立對非法傾倒拆建廢料活動管理成果評估機制。香港在利用新技術（如視頻監控）治理非法傾倒拆建廢料活動上進行了持續的投入，每年不斷增加黑點數量。我們至今仍未發現較爲全面的評價標準，進而無法選擇更爲有效的手段對非法傾倒拆建廢料活動進行治理。因此，成果評估機制是急需且必要的。

此外，更多的政府部門應該加強合作，共同治理非法傾倒拆建廢料活動，主要包括地政總署、土木工程拓展署、漁農自然護理署、環境保護署、食物環境衛生書、規劃署。由於傾倒活動的轉移，它會出現在不同的土地利用類型上，涉及到不同部門的管理範疇，不僅會增加額外的檢測困難，同時也給合法性的判定帶來挑戰。拆建廢料的流通是一個有源頭和目的地的閉環，涉及到不同部門。追蹤拆建廢料的源頭和目的地有助於拆建廢料的管理。因此，多部門合作是必要的。

1. Introduction

Illegal dumping resulting from rapid urbanization is a global issue. In Hong Kong, more than 40,000 tons of Construction and Demolition (C&D) materials are generated daily by local industries (Statistics Unit of EPD, 2020). Inappropriate disposal of construction waste leads to serious problems, including but not limited to land wastage, environmental pollution and the threat to life and property. In Hong Kong, illegal depositing of construction and demolition (C&D) materials became the third largest pollution complaint in Hong Kong in 2020. With the upcoming saturation of landfill capacity and the implementation of Municipal Solid Waste Charging in 2024, it may incur more illegal dumping activities, including construction wastes. Therefore, there is an urgent need to monitor illegal dumping of C&D.

In Hong Kong, considerable efforts have been made to combat illegal dumping. The Environmental Protection Department (EPD) has developed a Real-Time Tracking and Monitoring of Vessels (RTTMV) system to monitor illegal dumping at sea and a Ticket System for construction waste for public works projects (Lu et al., 2019). To further enhance illegal dumping detection, the EPD commenced a trial scheme to install surveillance camera systems in 2015, and more cameras are in the plan. Meanwhile, unmanned aerial vehicles (UAVs) are

used by the Lands Department to assist in illegal dumping management. Big data is also proposed against illegal dumping by identifying possible drivers using behavioural indicators and data analytics (Lu et al., 2019). However, the current strategies mainly focus on the black spots for illegal dumping. Hence, illegal dumping activities outside the monitoring areas may escape from inspection unless they are reported by the public or occasionally caught through regular patrols. Due to the stealth and intentional evasion of illegal dumping activities, it is difficult to timely trace them and take rapid action to manage the illegal dumping of C&D.

By utilizing the high spatio-temporal PlanetScope images, this research aims to develop a framework for the timely detection of illegal dumping of C&D. The high spatial resolution makes illegal dumping activities detectable, and the high temporal resolution enables frequent monitoring possible. Cloud contamination is an essential issue for optical images to detect illegal dumping in Hong Kong, which will not only lead to invalid observations but also false alarms. In addition, how to automatically detect the changes caused by illegal dumping is also a challenge. More importantly, whether the dumping activities are legal should be further determined.

2. Objectives of the Study

(1) To develop an automatic cloud detection model for screening the quality of daily PlanetScope images to support illegal dumping detection.
(2) To develop an unsupervised model to automatically detect suspicious illegal dumping with daily high-quality PlanetScope images.
(3) To develop a rule-based decision system to facilitate concerned departments in illegal dumping management using Geographic Information System (GIS).

3. Research Methodology

The framework for detecting illegal dumping of C&D consists of three main parts, cloud detection, unsupervised change detection, and decision system (Figure 1). Prior to this, data preprocessing was also introduced to account for the large data volume, intensive computation, as well as variability of images from the PlanetScope satellite constellation. Details are given follow.

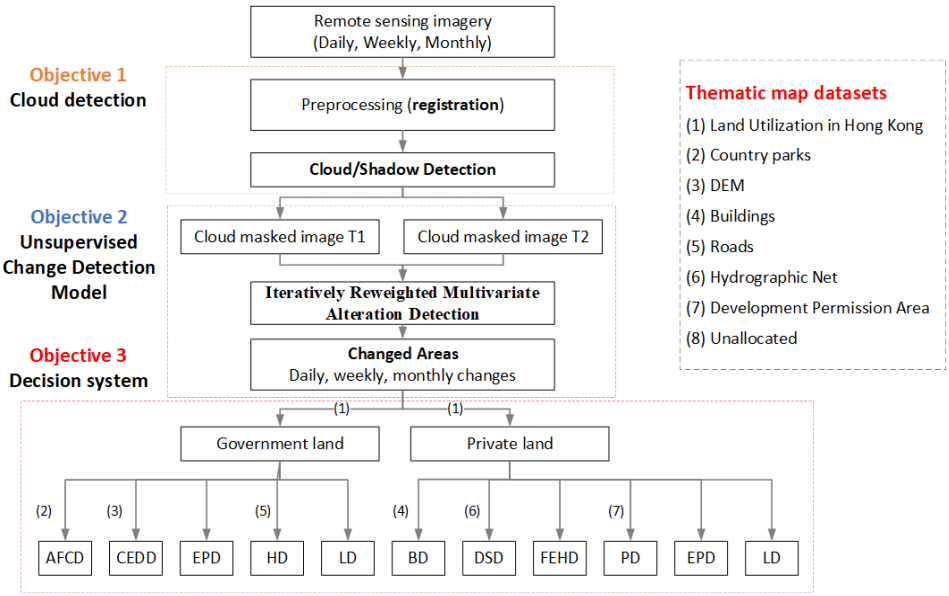

Figure 1. Flowchart of the proposed framework for illegal dumping activities detection. (AFCD: Agriculture, Fisheries and Conservation Department, CEDD: Civil Engineering and Development Department, EPD: Environmental Protection Department, HD: Highways Department, LD: Lands Department, BD: Buildings Department, DSD: Drainage Services Department, FEHD: Food and Environmental Hygiene Department)

3.1.Preprocessing

We built a custom grid system to cover most of the terrain in Hong Kong (Figure 2), from which 85 grids with terrain coverage were selected to clip the PlanetScope images to create image tiles. The grid-based strategy aims to save storage and computational resources, and illegal dumping detection on a tile rather than an entire image over Hong Kong is also more user-friendly, allowing the detection on images with arbitrary sizes and focusing concern on key areas (e.g., black spots).

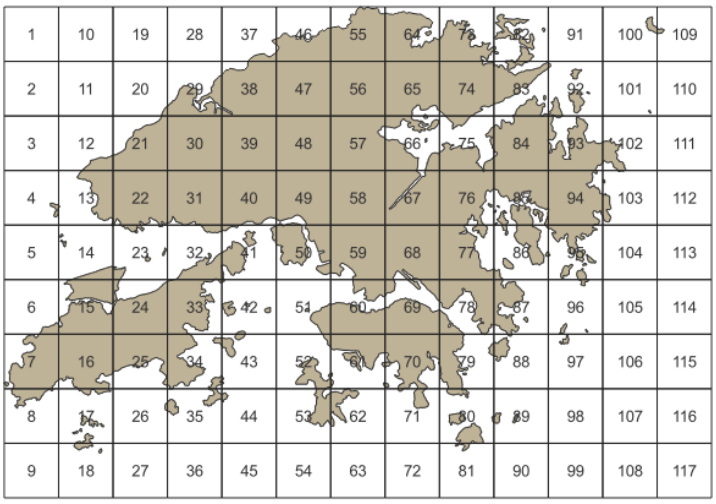

Figure 2. Grid system for clipping PlanetScope images.

Image preprocessing was performed on a grid basis (Figure 3). Image tiles within a grid were first projected into the EPSG2326 projection. Image tiles on the same day but from different PlanetScope image scenes were mosaicked using histogram matching to construct daily image tiles.

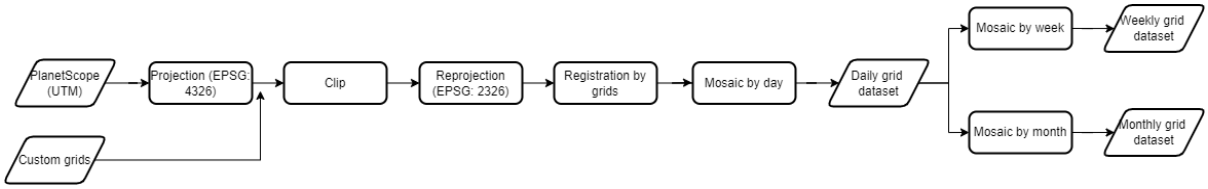

Figure 3. Image preprocessing based on grids.

3.2.Cloud detection

Tailored for PlanetScope images, we developed a two-step strategy to detect clouds and cloud shadow based on a principle of gradual refinement (Figure 4). The first step is to obtain the initial cloud and shadow mask for tile images with classic HOT index (Zhu and Helmer, 2018) and shadow index (Luo, 2008), respectively. The temporal information was also integrated for clouds and cloud shadow detection in the first step. Clouds or cloud shadows will bring a higher temporal variability of surface reflectance, and they can be viewed as the outliers in time dimension. Images were divided into blocks, from which those blocks with a higher standard deviation were selected as the candidate outlier blocks. Furthermore, in visible and NIR bands, pixels with reflectance higher than 95th percentiles were screened out as clouds, while lower than 5th percentiles were screened out as cloud shadow. In the second step, we further refine the masks by integrating morphological processing and matching cloud objects with cloud shadows. In addition, the screened clouds and cloud shadow were used to evaluate image quality with ratios of clouds/cloud shadow, clear area, and background.

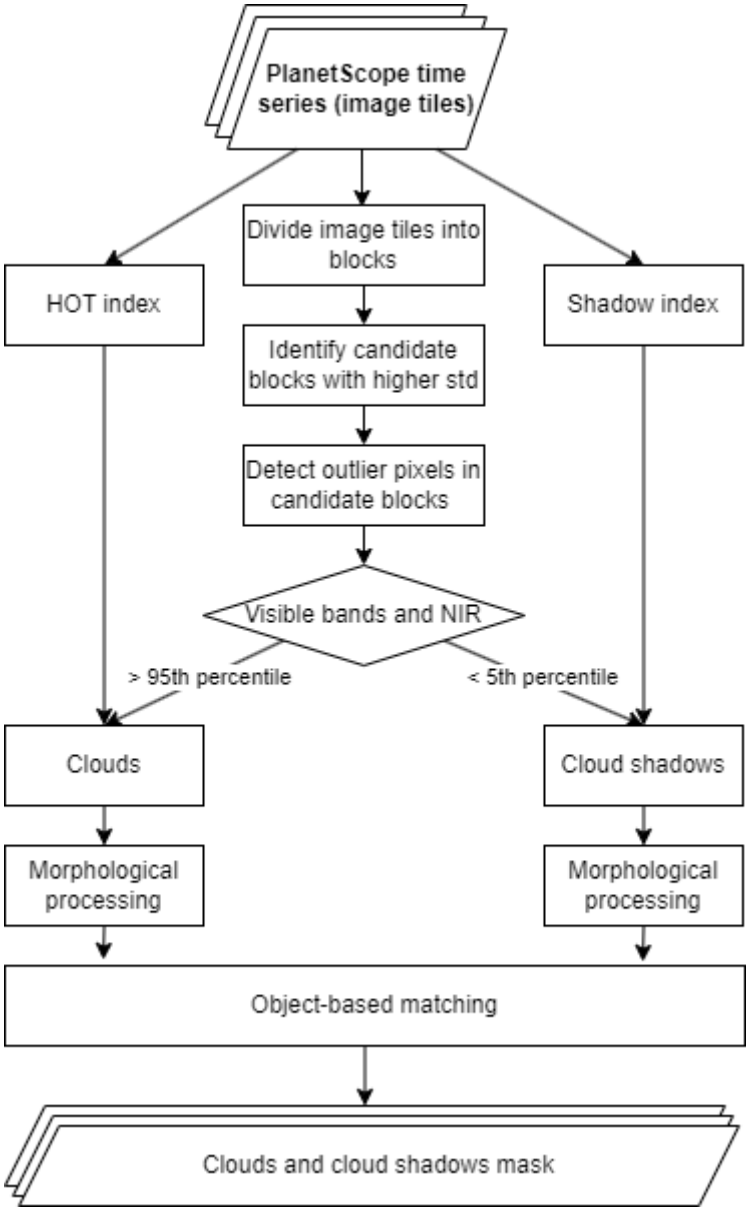

Figure 4. Flowchart of PlanetScope image cloud and cloud shadow detection.

3.3.Land cover change detection

The iteratively reweighted multivariate alteration detection (IRMAD) was applied for change area detection (Nielsen, 2007) between bi-temporal images. Based on Canonical Correlation Analysis (CCA), the weights for small changes were iteratively adjusted to be higher, and the background/change areas were clustered using KMeans. IRMAD can automatically extract the change areas without the requirement of samples. Affected by the image quality of PlanetScope (e.g., resolution, bias in image registration, different viewing angles, shadows (building, mountain)), IRMAD produced more false alarms, especially in urban areas.

To reduce the number of false alarms, we developed a coding strategy based on IRMAD (Figure 5). The coding strategy assumes that the land cover changes caused by illegal dumping do not recover within a short period of time (less than the valid observation cycle of PlanetScope), meaning the bi-temporal change within the short period can only occur once. We took an adaptive short period rather than a strict one. In this project, we adopted the date range covering four consecutive images (T1, T2, T3, and T4) as the short period (minimum 4 days and maximum 1 year) based on image quality. Each time an image on a new date will be examined, and the areas and the date of changes will be recorded. After examining all the images, the changes that occurred on the earliest date (start date) are kept as the results based on the assumption that illegal dumping activities will not change the land cover more than once in the same areas, and the latest date of change was taken as the end date of illegal dumping.

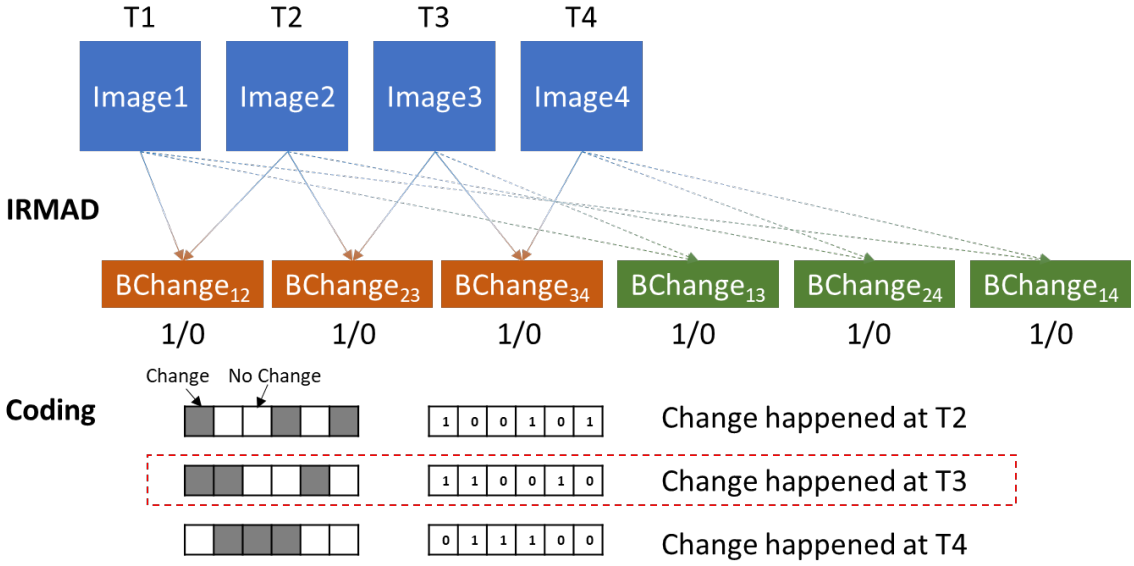

Figure 5. A coding strategy for change area detection.

3.4.Decision system

The decision system includes two steps. In the first step, the changes detected by IRMAD with the coding strategy will be filtered to further confirm whether they are from illegal dumping. It is assumed that illegal dumping happens on lands with a low altitude (average DTM<100m) and an insignificant head (DTM head<1.5m). Besides, the lands resulting from illegal dumping should not be with vegetation (NDVI<0.1) or in water (NDWI<0.0). Through the first part, the false alarms from the changes due to vegetation growth, different water levels, and those changes happening in the mountains can be removed, and all suspicious illegal dumping can be obtained.

In the second step, the land use map was used to determine whether the dumping activities were legal or not. The basic decision-making rules are:

(1) Dumping activities hardly happen in areas with many people living, working or for public recreation unless legal. Otherwise, the public will report illegal dumping if noticed.

(2) Dumping activities in the lands for large-scale facilities, such as government, institutional and community facilities, transport facilities and science and technology parks, hardly happen without permission.

(3) Dumping activities hardly happen in water areas, such as fishponds or reservoirs, only if allowed. Otherwise, they tend to be false alarms.

(4) The dumping activities in the acknowledged lots recorded by the government are legal.

The second part will output the areas where suspicious illegal dumping activities happen. The land use information will be embedded as an attribute for duty assignment for associated departments if necessary.

4. Research Results/Findings

4.1.Cloud detection

Compared to the cloud masks released by PlanetScope, our proposed method can accurately detect clouds and cloud shadows (Figure 6). Accurate cloud detection can effectively remove false alarms due to cloud contamination. It also provides information to evaluate image quality, which is important for image selection when conducting change detection among the four adjacent valid observations (see the section of *land cover change detection* in the research methodology part).

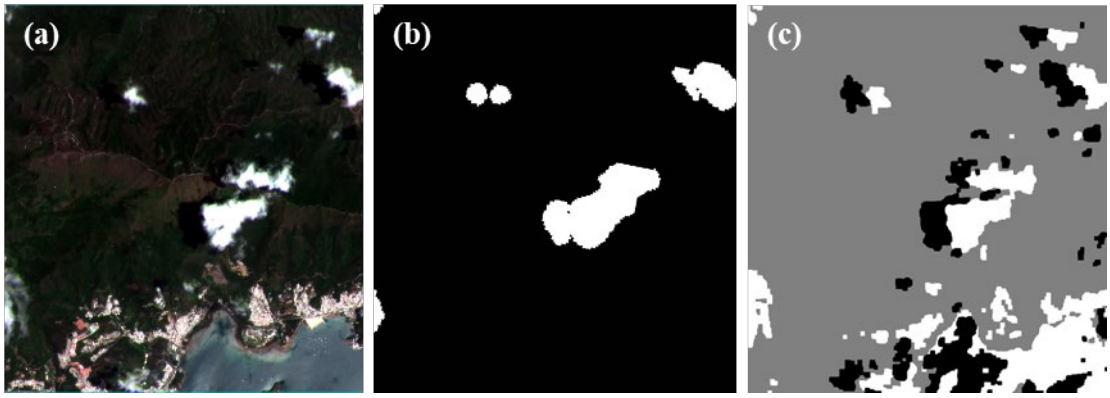

Figure 6. An example of cloud detection using the proposed method over the image on May 22, 2021 on tile 65. (a) True colour PlanetScope image, (b) cloud mask released by PlanetScope (white areas indicate clouds and cloud shadow), (c) clouds detected by ours (white areas indicate clouds, black areas indicate cloud shadows, while grey areas indicate to be clear)

4.2.Changed areas detection

In this part, we aim to detect land cover changes as much as possible, avoiding omissions which cannot be remedied in the subsequent steps. These changes contain many false alarms, such as vegetation regrowth, water color change due to different water levels, and changes in ongoing construction sites. Some changes, such as vegetation degradation, similar to those resulting from illegal dumping, were also included, but they were mainly in the mountains. We detected the change areas on 60 tiles to cover most lands of Hong Kong (Figure 7). The tiles covering small islands in Outlying Islands were ignored, considering the faint possibility of illegal dumping in those areas and the usage of computation resources.

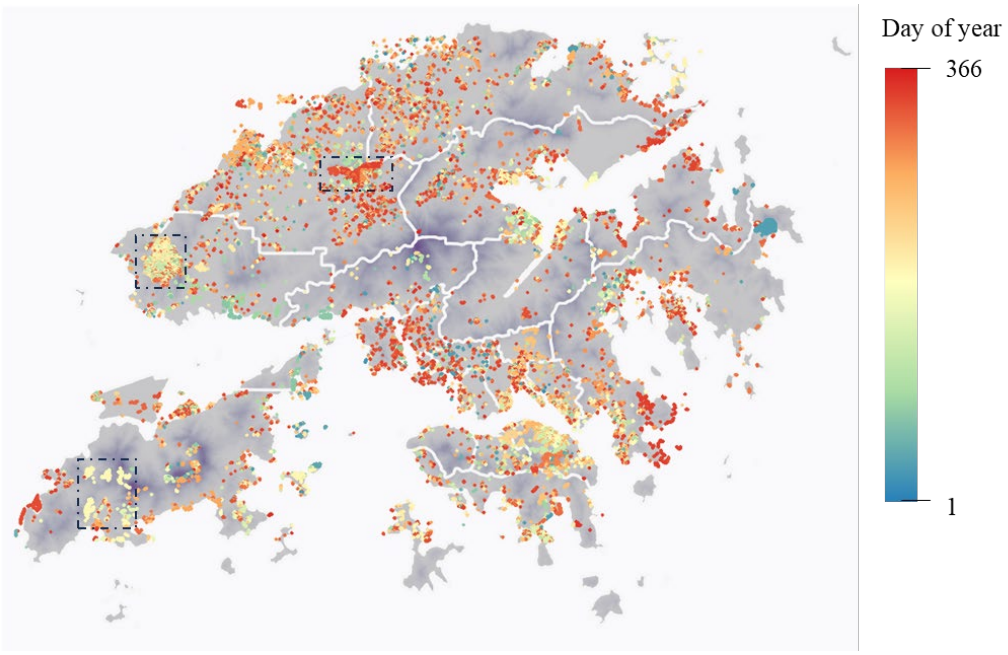

Figure 7. Change areas detected by IRMAD with the coding strategy, and many changes were detected in the mountains (outlined by rectangles). (The base map is the 5m DTM from the Lands Department)

4.3.Illegal dumping detection

Based on the change areas detected by IRMAD with the coding strategy, the false alarms were further removed using the decision system, and the final suspicious illegal dumping areas can be obtained. The result from the one-step decision system shows that it can significantly remove false alarms, especially in mountain areas (Figure 8a). Furthermore, the result from the two-step decision system shows that the changes in the airport and Gei Wais can be removed. The changes in areas where residential and government buildings cluster, including Sham Shui Po and Eastern District, are also excluded (Figure 8b). Finally, we obtained approximately 3441 sites for suspicious illegal dumping with a total area of 51.9318 ha. We collected nineteen

samples (Figure S1) according to the acknowledged notifications (Table S1) in 2021 to verify their accuracy, and the result shows that 9 out of 19 dumpling sites were successfully detected and C&D disposal activities had not yet started on the other 10 sites by the end of 2021. Partial results in the North East New Territories was given below (Figure 8c).

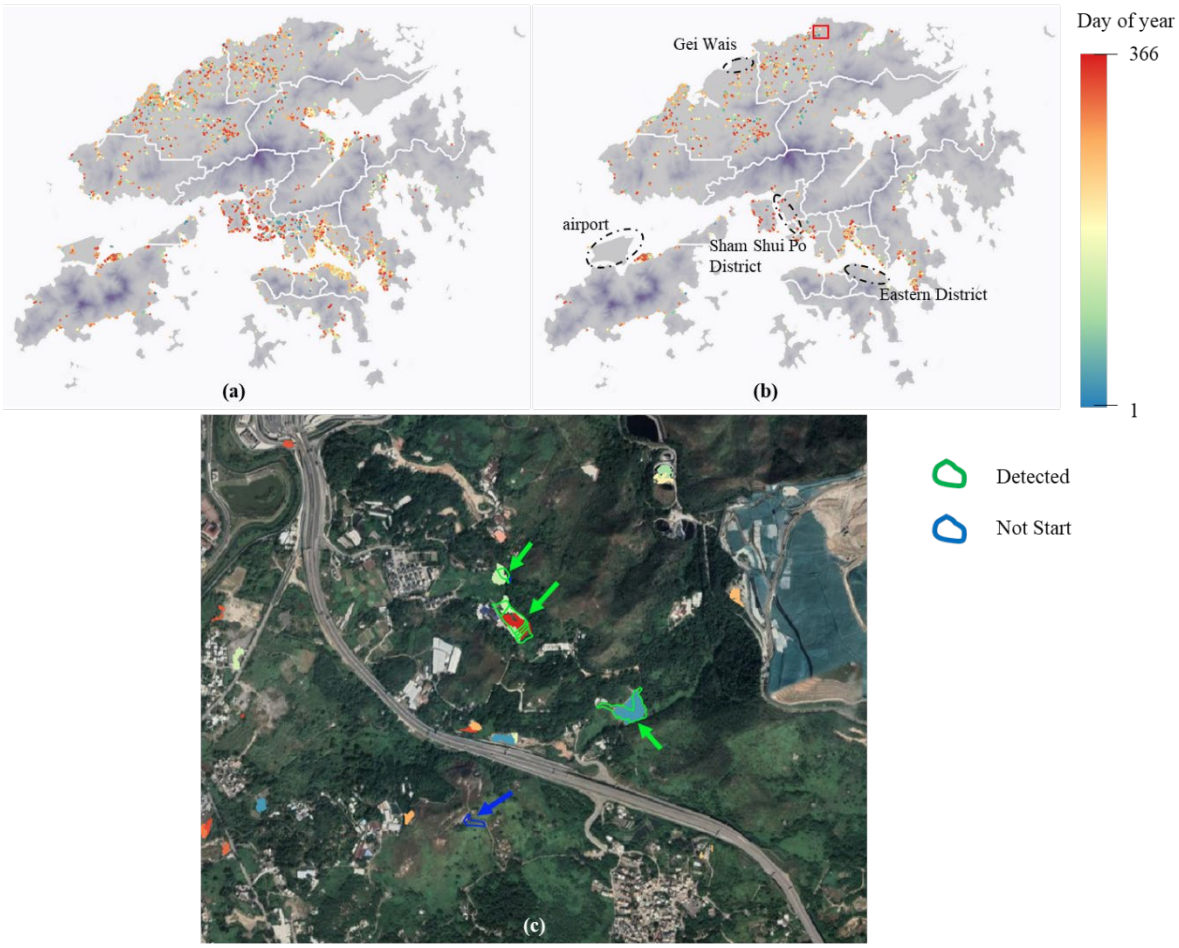

Figure 8. Suspicious illegal dumping detection using the proposed framework with the one-step (a) and two-step (b) decision system. (Two-step decision system integrates the land use information and removes the changes in the airport, Gei Wais, Sham Shui Po District and Eastern District) (c)an example of successfully detecting the acknowledged lots for C&D disposal by the Hong Kong government.

In addition, we also calculated the distribution of land use where suspicious illegal dumping activities happened. The result shows that most suspicious illegal dumping activities can be found in vacant land or construction in progress, followed by agricultural land, warehouse and open storage, grassland, rural settlement, and industrial land (Figure 9). It is reasonable to deposit C&D in the ongoing construction site or the open storages, and changes that happen in these areas tend to be legal, but further checks should be conducted due to a mixture of vacant land and construction in progress in the land use scheme. Beyond that, suspicious illegal dumping was also found in agricultural land, grassland, and rural settlements, which should be

paid more attention. Also, we tried to figure out the date patterns for illegal dumping and found that there are 190 days in 2021 on which illegal dumping activities were detected (Figure 10), suggesting that monitoring illegal dumping all year round is necessary, particular in the second half year.

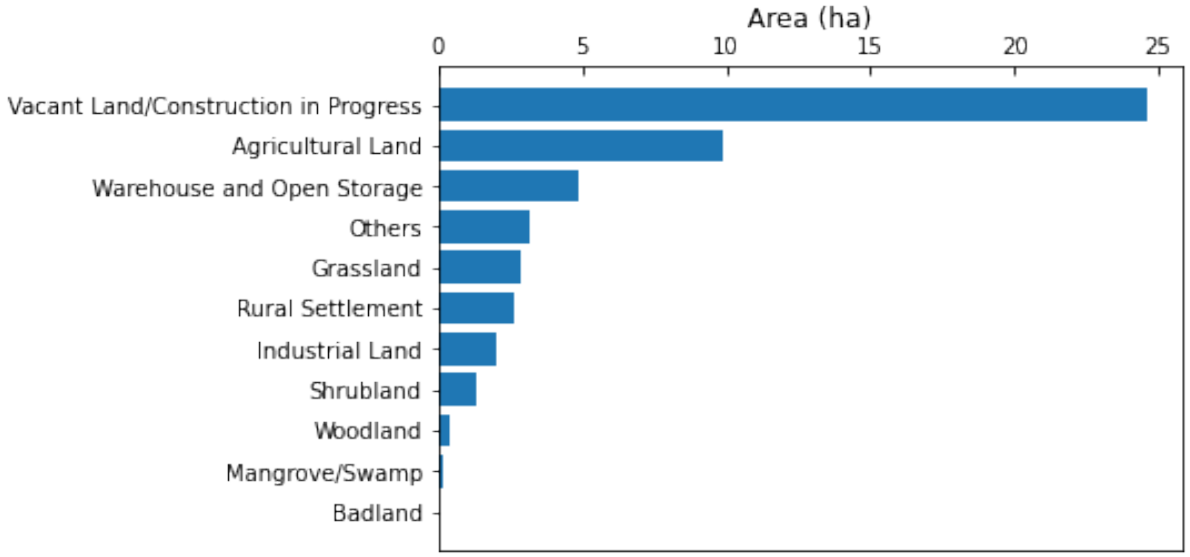

Figure 9. Distribution of land use for suspicious illegal dumping activities.

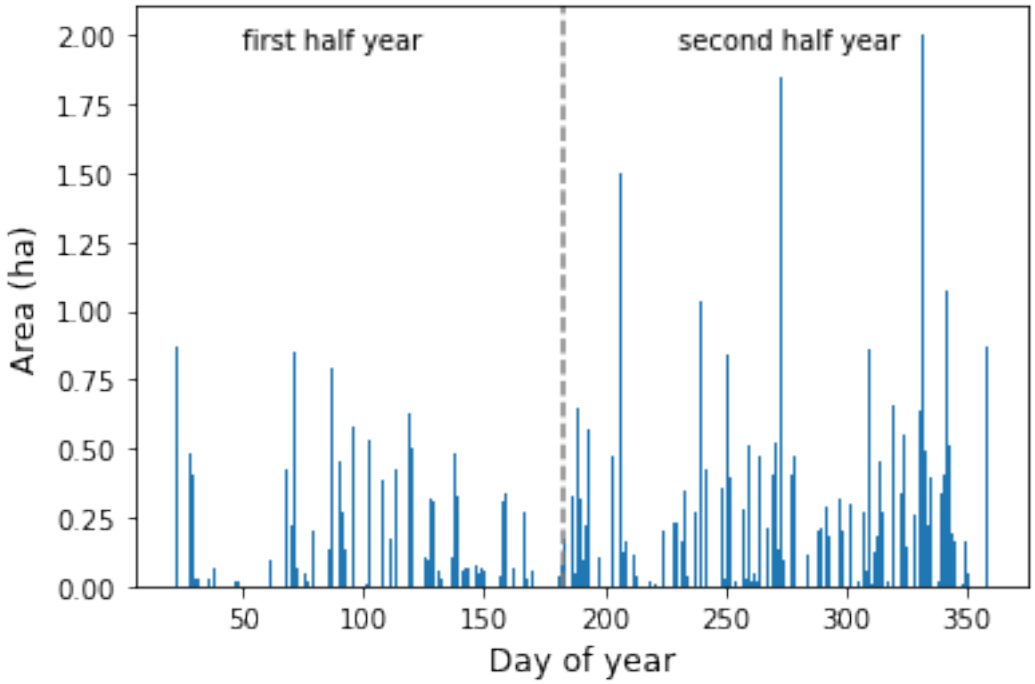

Figure 10. Distribution of dates for illegal dumping.

For the eighteen districts of Hong Kong, the suspicious illegal dumping of C&D was mainly found in Yuen Long and North, especially in vacant land/construction in progress, agricultural land (Long Valley (i.e., DD92 830), Chow Tin Tseun (i.e., DD82 226), Chung Chai Yuen (i.e., DD91 2071), Tsiu Keng (i.e., DD100 327), Cheung Lek (i.e., DD100 81), etc) and warehouse

& open storage (Figure 11a). Illegal dumping was also detected in grassland and rural settlements in both districts, and even in shrubland in Yuen Long.

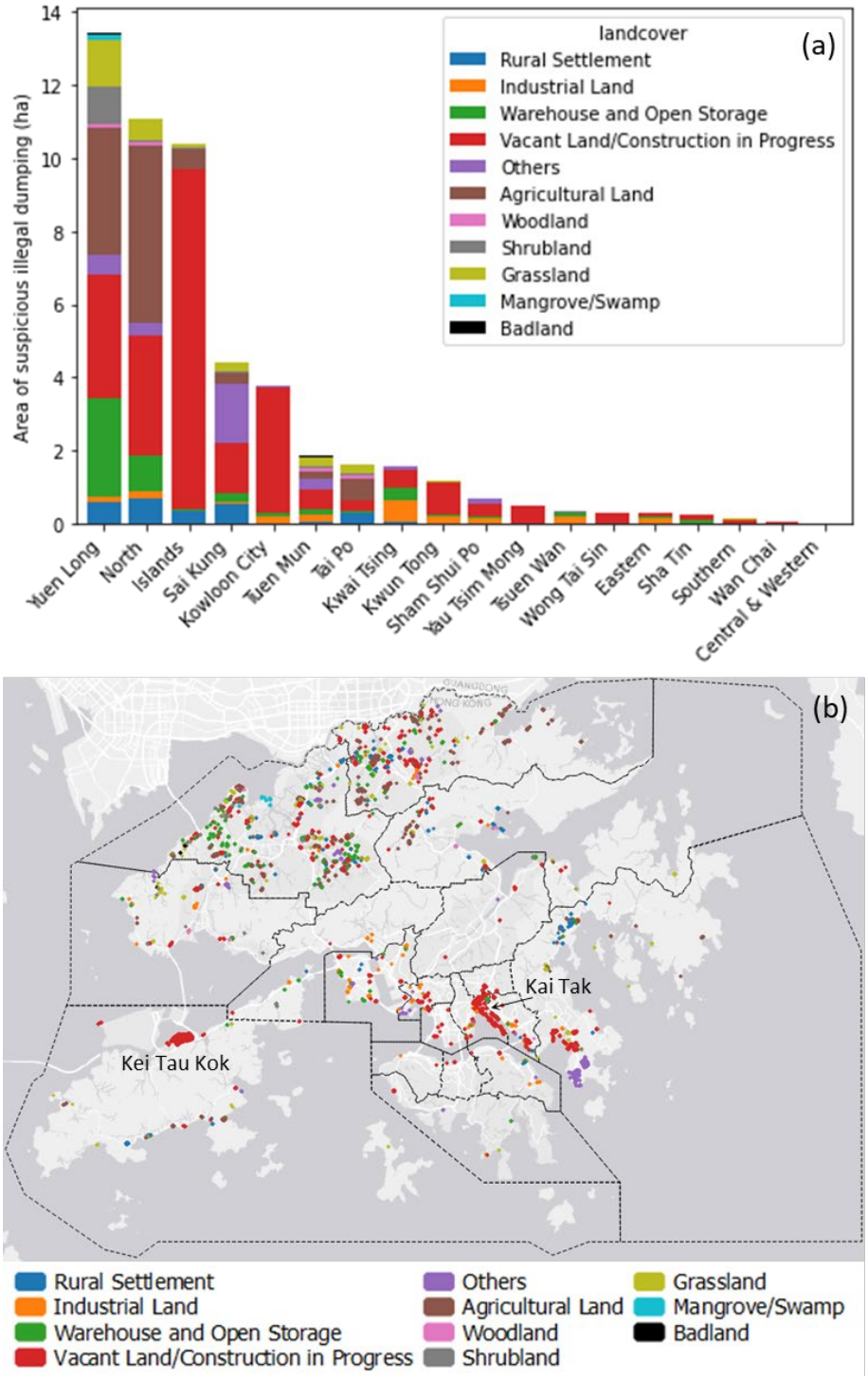

Figure 11. Bar chart (a) and map (b) of suspicious illegal dumping in different land cover in 18 districts of Hong Kong

In the Islands district, most of the suspicious illegal dumping was from the land reclamation in Kei Tau Kok, and the suspicious illegal dumping in agricultural land and rural settlement were

from the southern villages of Lantau Island (Figure 11b). Similar to the Islands, most of the suspicious illegal dumping in Kowloon City was detected in construction in progress (Kai Tak). In Sai Kung, the suspicious illegal dumping detected was mainly from the construction in progress (Tseung Kwan O) and temporary public filling (Fat Tong O).

4.4.Implementation of the decision-making system

We have already collected the Land Utilization Map of Hong Kong in 2021 (LUMHK), digital land boundary map (iC1000), the Digital Terrain Model (DTM), the Acknowledged Notification of depositing activity or land filling of construction waste (AN) and the District Boundary of Hong Kong (DBHK), etc. Together with the results of illegal dumping detection, we built a database in the form of geojson, which contains the following key information (Table 1).

Table 1. Fields of database for the decision-making system. (DD: demarcation district)

Field name	Datatype	Example	Description	Source
ID	int	25	System index	System generation
Lot_ID	list of string	DD# 91 Lot, 2071; …	Lot id where suspicious illegal dumping was detected	iC1000[1]
Areas (m^2)	double	325	Area of C&D deposal	Section 4.3
Slope (degree)	double	30.1	Slope of the ground	DTM[2]
Landcover	int	73	Code of different land uses	LUMHK[3]
Start_date	string	2021-03-25	Date when illegal dumping started	Section 4.3
End_date	string	2021-12-15	Date when illegal dumping ended	Section 4.3
Start_doy	int	12	Day of year when illegal dumping started	Section 4.3
End_doy	int	361	Day of year when illegal dumping ended	Section 4.3
District	String	Sha Tin	In which district the suspicious dumping happened	DBHK[4]
Acknowledged	List of string	DD 91 Lot, 2071; …	Lot_ID of lots acknowledged	AN[5]
Departments	List of string	LD, EPD	Associated departments	-
Tile_ID	int	64	Tile id	Section 3.1
geometry	polygon		Suspicious illegal dumping areas	Section 4.3

1. source: https://portal.csdi.gov.hk/geoportal/#metadataInfoPanel
2. source: https://data.gov.hk/en-data/dataset/hk-landsd-openmap-5m-grid-dtm
3. source: https://data.gov.hk/en-data/dataset/hk-pland-pland1-land-utilization-in-hong-kong-raster-grid/resource/18bca3e9-29ae-4dfb-85e9-a8822c8fbe22
4. source: https://www.had.gov.hk/psi/hong-kong-administrative-boundaries/hksar_18_district_boundary.gml
5. source: https://www.epd.gov.hk/epd/english/environmentinhk/waste/prob_solutions/wdaodetail_LP02RN00424506.html

In particular, the results of the illegal dumping detection (see section 4.3) provided the area of C&D deposal, and the deposal areas can be further converted into vectors (as the geometry field, Table 1). The start date and end date of suspicious dumping can also be obtained (see Section 3.3). Other fields can be obtained from the ancillary documents, such as the Lot_ID from the Digital Land Boundary Map, using overlay analysis (join, intersect, etc.). Details of the sources of the different fields are given in Table 1.

The database assembles all related information on the suspicious illegal dumping, from which the areas of interest can be searched, visualized, and analysed using QGIS or custom codes (e.g., PYTHON), even for determining the scope of duties. Considering the fuzzy boundary of works within different departments and professional knowledge for determining the scope of duties, the final duties should be determined and confirmed by different departments based on the ordinances. Therefore, this research has only shown an example of how to use the decision-making system for determining the scope of duties. Slope safety is an important issue concerned by the CEDD, and illegal dumping on unstable slopes can lead to landslides and should be paid attention to by the CEDD. To this end, we calculated the slope of the ground using the DTM data (Figure 12), and illegal dumping on the slopes with a large angle (24 degrees for reference, ~ 80% of the sand angle of repose) were pushed to the CEDD. The result is shown in Figure 13. With this information, the CEDD can take quick action to check the safety of the slope and eliminate hidden hazards. Other departments can also use the decision-making system to tailor services to their needs.

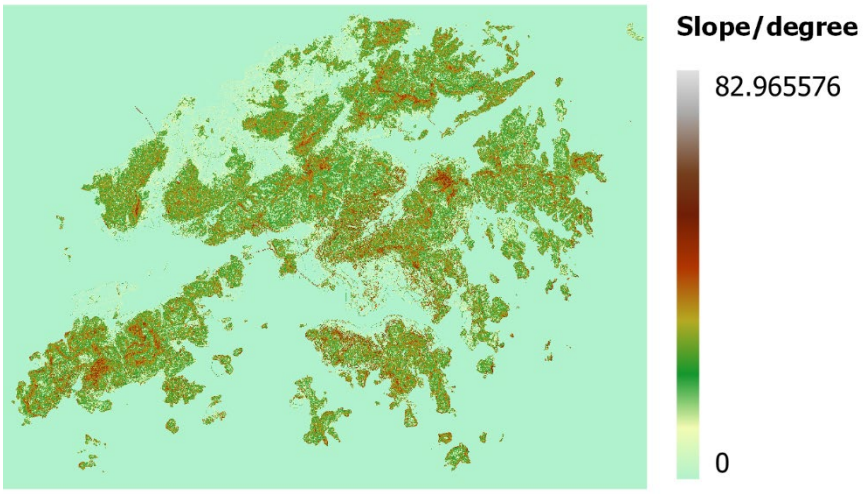

Figure 12. Slope calculation with the DTM data using QGIS with z factor of 1.0.

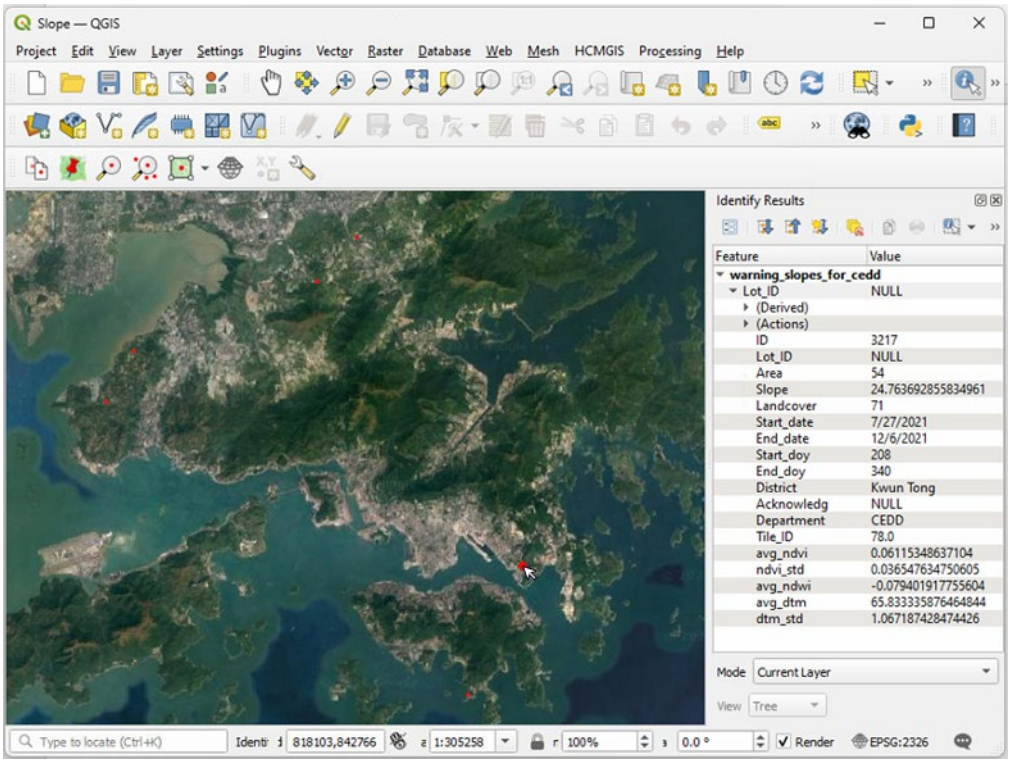

Figure 13. Example of slope safety warnings for CEDD using the decision-making system.

5. Policy Implications and Recommendations

The proposed framework aims to screen all suspected illegal dumping activities in Hong Kong using high-resolution satellite images and a decision system, thus assisting the Hong Kong government to effectively and efficiently manage illegal dumping of C&D. After processing 2096 image scenes with a total volume of 801GB data in 2021, we detected approximately 3441 sites of suspected illegal dumping with an area of 51.93ha in the 18 districts of Hong Kong. In addition, we also offer the following suggestions.

Overall monitoring of illegal dumping of C&D

Surveillance camera systems, reports from the public and patrols are the main measures taken by the Hong Kong government to combat illegal dumping of C&D. The distribution of about 50[*] black spots by 2018 shows that the current measures mainly focus on urban areas (Figure 14), while the results of suspicious illegal dumping (see section 4.3) reveal that most of them are likely to be in rural areas. In comparison, there are blind zones of illegal dumping that cannot be monitored by current measures and are therefore missed. Also, patrols and reports from the public focus on the cases in accessible areas. Illegal dumping in rural areas or on

[*] This number was up to 115 by 2019 according to the response to actions from the legislative council panel on environmental affairs, https://www.legco.gov.hk/yr19-20/english/panels/ea/papers/ea20191028cb1-192-1-e.pdf

private land blocked by fences is impossible to detect. Besides, the affected areas in rural sites tend to be large, which can cause more serious problems. Therefore, overall monitoring by remote sensing is more effective than spot surveillance.

The results of suspicious illegal dumping indicate the effectiveness of remote sensing in the overall monitoring of illegal dumping. Despite the provision of suspicious illegal dumping, it provides a baseline of illegal dumping in Hong Kong as a whole, making it possible to improve current measures in terms of selecting suspicious site for installation of surveillance cameras and patrols, and taking prompt action against illegal dumping, such as prosecutions, etc.

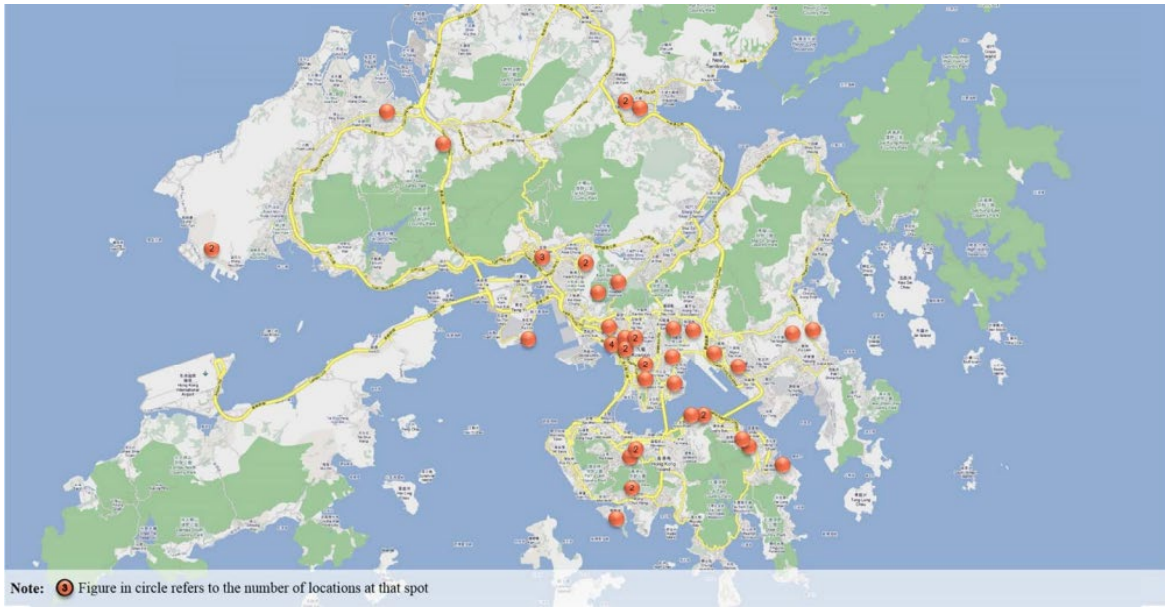

Figure 14. Surveillance Camera System Installed at Construction Waste Fly-tipping Black Spots. (Approximately 50 black spots by 2018, source: LEGISLATIVE COUNCIL PANEL ON ENVIRONMENTAL AFFAIRS: Enforcement Against Illegal Land Filling and Fly-tipping of Construction Waste, available on: https://www.legco.gov.hk/yr17-18/english/panels/ea/papers/ea20180326cb1-703-3-e.pdf)

Performance evaluation mechanism

At present, the Hong Kong government evaluates the effectiveness of existing measures to deal with illegal dumping by the number of complaints received by the authorities or the number of prosecutions (Figure 15). This exhibits what the Hong Kong government has done, without giving any information about areas which were not covered the government's effort (see the Research results). Consequently, it is unclear whether the indicators of case numbers are valid for assessing the effectiveness of current policies. Without a performance evaluation mechanism, we may be blindly investing in the existing policies.

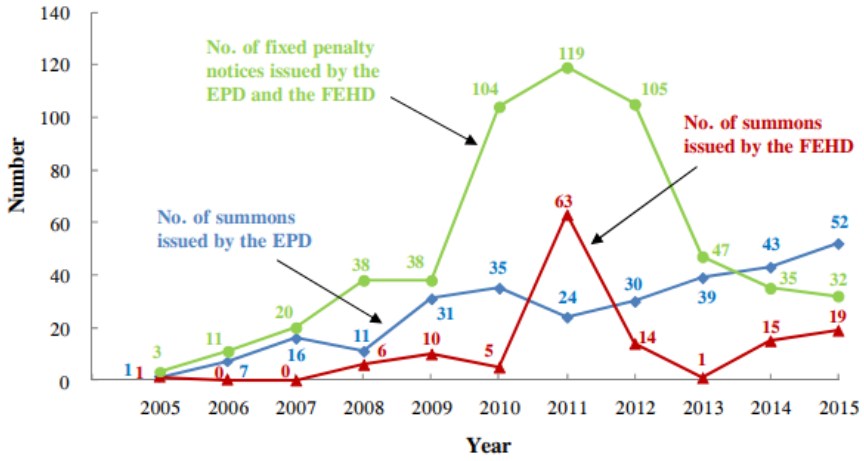

Figure 15. Number of prosecution actions taken against illegal dumping of C&D materials on government land (2005 to 2015). (Source: chapter 4: Management of abandoned construction and demolition materials, available on https://www.aud.gov.hk/pdf_e/e67ch04.pdf)

The establishment of a performance evaluation mechanism should be based on the overview of the illegal dumping of C&D in Hong Kong, and the evaluation criteria should include not only the accurate location of the illegal dumping sites, but also the tracking of the subsequent efforts to restore the ecological environment of the affected areas. The proposed framework with daily PlanetScope imagery provides year-round monitoring, including the potential dates when illegal dumping activities took place or ended, providing an opportunity for performance evaluation in spatio-temporal aspect.

Cross-department cooperation

The framework has identified illegal dumping across 11 types of land use/land cover in the 18 districts of Hong Kong. Different land covers are under the jurisdiction of different departments, and illegal dumping prosecutions can be initiated by different departments based on their jurisdiction (Figure 13). In-depth cooperation can sufficiently maximize the benefits for partners. Traditional inter-department cooperation lies in information sharing. This project explored the possibility of cooperation in knowledge sharing rather than information sharing to support the management of illegal dumping. The main difference between knowledge sharing and information sharing in the management of illegal dumping is to unify the process of illegal dumping detection based on the knowledge gained from the information sharing, facilitating quick action to handle affairs (Figure 16).

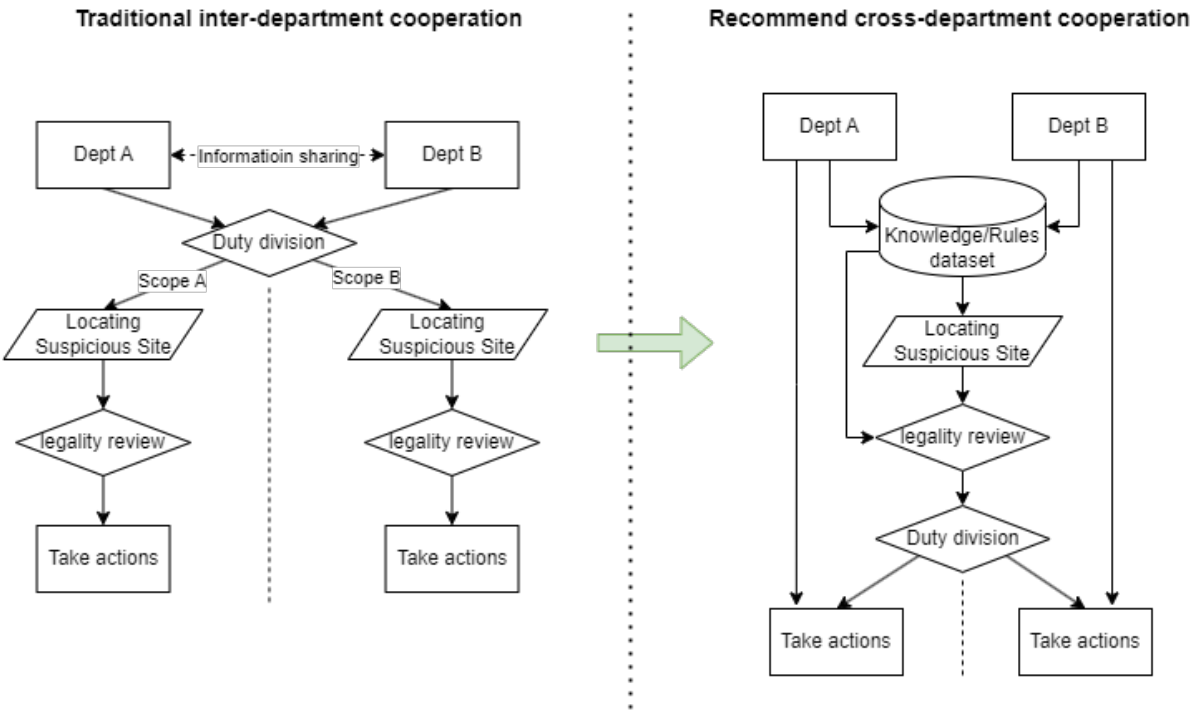

Figure 16. Mode comparison of traditional cooperation and recommended cooperation between different departments.

6. Details of the Public Dissemination held

The project team presented the developed method and preliminary results in the 2023 Quantitative Remote Sensing Forum (第六屆全國定量遙感學術論壇) in Chengdu, China

7. Conclusions

To timely detect illegal dumping activities to support livable city construction, this research proposed a framework based on PlanetScope images which have both high spatial and temporal resolutions. Specifically, this research addressed the difficulties in cloud screening, change area detection from high-resolution images, and illegal dumping identification from the change areas. We found that:

(1) The automatic cloud and shadow detection approach can effectively detect the clouds and cloud shadow for PlanetScope images and obtain a better result than the cloud mask released by PlanetScope.

(2) The strategy of IRMAD and coding can effectively detect the change areas without requiring samples, making illegal dumping detection over a large scale possible.

(3) The two-step decision system can significantly remove false alarms and narrow down suspicious areas for illegal dumping.

8. Main References

Environmental Protection Department (EPD). 2020. Monitoring of Solid Waste in Hong Kong Waste Statistics for 2019. Available at: https://www.wastereduction.gov.hk/sites/default/files/msw2019.pdf.

Lu, W. 2019. Big data analytics to identify illegal construction waste dumping: A Hong Kong study. *Resources, Conservation and Recycling, 141*, 264-272. https://doi.org/10.1016/j.resconrec.2018.10.039.

Luo, Y., Trishchenko, A. P., & Khlopenkov, K. V. 2008. Developing clear-sky, cloud and cloud shadow mask for producing clear-sky composites at 250-meter spatial resolution for the seven MODIS land bands over Canada and North America. *Remote Sensing of Environment*, 112(12), 4167-4185.

Nielsen, A.A. 2007. The regularized iteratively reweighted MAD method for change detection in multi-and hyperspectral data. *IEEE Transactions on Image Processing, 16*, 463-478.

Zhu, X., & Helmer, E. H. 2018. An automatic method for screening clouds and cloud shadows in optical satellite image time series in cloudy regions. *Remote sensing of environment*, 214, 135-153.

Appendix A

Table S1. Samples collected from the acknowledged notification. (* *Lot location can be found on the website: https://www.map.gov.hk/gm/map/*)

No.	Ref No.	District	Lot No.*	Date of depositing activity	Estimated area (m^2)	Estimated height (m)	Detected or not
1	LP02/RN/00425233	North	396 S.A RP, 396 S.A ss.1 RP, 396 S.A ss.1 S.A, 396 S.A ss.1 S.B, 396 S.A ss.2 S.A, 396 S.A ss.2 RP, 396 S.A ss.3, 396 S.A ss.4, 396 S.A ss.5, 396 S.A ss.6, 396 S.A ss.7, 396 S.A ss.8, 396 S.A ss.9, 396 S.A ss.10, 396 S.A ss.11, 396 S.A ss.12, 396 S.A ss.13, 396 S.A ss.14, 398 S.B ss.2, 398 S.B ss.3, 398 S.B ss.4, 398 S.B ss.5, 398 S.B ss.6, 398 S.B RP and 408 R.P in DD 41	23/12/2020 - 22/12/2021	4,550	1	**Y**
2	LP01/RN/00443629	North	Lot 389 R.P, 401 S.B and 418 S.C in DD 41	08/02/2021 - 07/02/2022	6,800	1	**Y**
3	LP01/RN/00444756	North	902 in DD 41	18/03/2021 - 17/03/2022	830	1	N
4	LP02/RN/00424506	North	1763 in DD 78	18/03/2021 - 17/03/2022	5,500	1.1	**Y**
5/6	LP01/RN/00444749	North	1171, 1172, 1178 and 1180 in DD 78	09/03/2021 - 08/03/2022	5,400	1.5	**Y**
7	LP01/RN/00444748	North	1179 and 1181 in DD 78	09/03/2021 - 08/03/2022	1,486	1.5	**Y**
8	LP03/RS/00423215	Islands	126 in DD 1 LM	29/09/2020 - 17/09/2021	60	2	N
9	LP01/RN/00439408	North	450 S.B RP in DD 83	16/11/2020 - 31/03/2022	875	4	N
10	LP01/RN/00440528	North	1177 in DD 78	06/11/2020 - 14/10/2021	929	1	**Y**
11	LP01/RN/00442218	Tai Po	185 in DD 8	06/12/2020 - 05/12/2021	365	1	N
12	LP01/RN/00443115	Tai Po	186 in DD 8	11/01/2021 - 10/01/2022	200	1.2	N
13	LP01/RN/00442363	North	1244 in DD 96	01/01/2021 - 31/12/2021	930	3	**Y**
14	LP01/RN/00442833	North	1219 in DD 96	01/01/2021 - 31/12/2021	980	3	N
15	LP01/RN/00443771	Tai Po	796, 798, 802 and 803 in DD 9	01/03/2021 - 31/01/2022	7,000	1.2	**Y**
16	LP01/RN/00442188	North	438 in DD 79	18/03/2021 - 17/03/2022	1,170	1.1	N
17	LP05/RW/00391561	Tuen Mun	162 S.C, 167, 168, 169, 175, 183 S.A and 183 R.P in DD 134	19/03/2021 - 18/03/2022	3,000	5	N
18	LP02/RN/00446388	Yuen Long	1660 in DD 117	01/06/2021 - 30/04/2022	750	4	N
19	LP02/RN/00444555	North	T37 S.A-S.C ss.1 in DD 76 TLL	30/07/2021 - 29/07/2022	200	1.5	N
20	LP01/RN/00450274	Yuen Long	1549, 1566 S.A and 1566 S.D RP in DD 117	15/09/2021 - 14/09/2022	2,200	4	**Y**

Figure S1. Samples collected for verification.