Digital Classification of Anthropogenic Features for Natural Terrain Hazard Assessment in the Quasi-natural Heritage Landscape of the Lin Ma Hang Lead Mine

Petra Lee*, Collette Tse, Francis Lee, Geoffrey Pook, Kevin Styles

Meinhardt Infrastructure and Environment Ltd., Hong Kong, China

*Corresponding author

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ABSTRACT

Much of the Hong Kong landscape consists of densely vegetated steep hillside and may give the impression of natural terrain untouched by man-made activities. However, much evidence of old human activities occurs in our vegetated landscape. The old lead mine workings in the Lin Ma Hang district of the northeast New Territories form a significant industrial heritage site now hidden by dense vegetation. Extensive old anthropogenic activities are seen in site reconnaissance. Most of the man-made features were formed during the mining period (1860-1960) and the WWII (1941-45) occupation of the mine site. Some features have more obscure origins associated with cycles of agricultural activity and settlement of more than 1000 years. The unique and diverse nature of the Lin Ma Hang hillsides provides an ideal case study to demonstrate the benefits of systematic assessment of anthropogenic features in Natural Terrain Hazard Assessment. Some of these man-made features may create impacts as potential adverse Hillside Pocket scenarios and require inventory and classification during natural terrain hazard and other geotechnical studies (Ho & Roberts, 2016). Over the past decade, the application of airborne LiDAR data for site characterization has grown significantly, in part due to advances in handling of very large data sets. Through 3D topographic models using LiDAR in combination with visual data, landforms are revealed and terrain classification is enhanced allowing identification of anthropogenic features of varying scale and origin within their geomorphological setting. The authors discuss the application of a digitally aided approach for terrain mapping with emphasis on the identification and classification of anthropogenic features based on size, type, origin, material, extent and location. These are classified within a Hong Kong-based framework of an 80 class classification following from Styles & Law (2012).

Keywords: Anthropogenic classification, Geospatial analysis, Natural terrain hazards, Mining and heritage

1 Introduction

1.1 Site Description

The Lin Ma Hang Lead Mine is an abandoned mine site operated intermittently from 1860s until 1962. The site is located in the Sha Tau Kok area of Hong Kong and north of the Robin's Nest (Hung Fa Leng, +492mPD). The lower slopes about the Lin Ma Hang and Sha Tau Kok Closed Frontier Roads on the border with Shenzhen. The Lead Mine is a significant historical mining site with a rich heritage linked with the local villages and a legacy of military conflict prior to and during WWII. The Natural Terrain Hazard Study Area (NTHSA) is the catchment above the entrance to the Mine Cavern Atrium to the north and south. The NTHSA has an area of some 4.5 ha and rises from an elevation of about +184mPD in the Cavern Atrium at the toe to +328mPD at the summit some 280m upslope (Figure 1).

Mining at the Lin Ma Hang can be traced back to the 1860s in the area of the Portuguese Workings adjacent to the Frontier Closed Road to Sha Tau Kok. The main mining activities commenced in 1913

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operating intermittently under the control of several mining companies until 1958. Small-scale working by the Japanese occurred from 1941 to 1945 during WWII. In 1962, the Government rescinded the mining lease and the mine was abandoned.

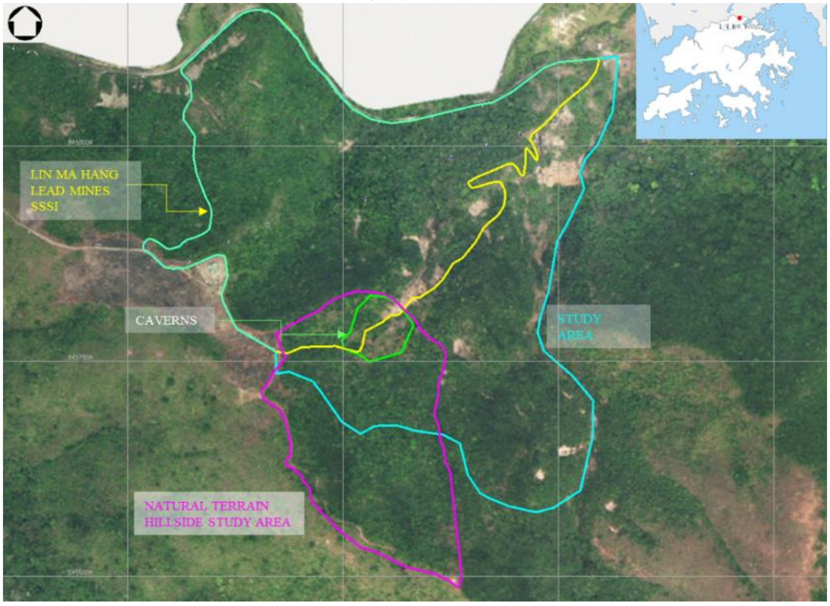

Figure 1: Site Layout (Cyan is the Project Study Area; green is the Mine Cavern; magenta is the NTHSA boundary; yellow is the SSSI boundary)

While the terrain in the NTHSA is generally masked by moderate to dense vegetation, extensive old anthropogenic features associated with cycles of agricultural activity, past mining, prospecting and military activity are seen during site reconnaissance. They consist of remnants of mining works including rubble walls, concrete platforms, building ruins, adits and shafts, open-cuts, water tanks, prospecting, military trenches and associated features. Remnants of very old agricultural practices also exist with rubble wall terraces and earthen step-form terraces. Together, the old anthropogenic features form a 'palimpsest' imprinted on the generally '*quasi-natural'* terrain settings across the Lin Ma Hang hillsides (Ho & Roberts, 2016).

1.2 Review of Terrain Classification

Regional and district scale systematic terrain classification in Hong Kong commenced in the late 1970s as part of the Geotechnical Area Studies Programme (Styles & Hansen, 1989). Over the following decade regional studies continued apace with many applications including computer generated maps (GEOTECS). The purpose of the GASP was to:

1. form a terrain classification inventory of physical land attributes (slope gradient, aspect, superficial/ in situ geology, man-made slope features, developed/undeveloped land, erosion and instability using the geomorphological mapping techniques of aerial photograph interpretation (API) and field mapping; and
2. better understand the nature and distribution of landforms and instability using a variety of user-oriented derivative maps for planning and land management purposes.

In the 1990s and early 2000s terrain related studies in Government (GEO) focused more on targeted investigation with a departure from systematic area-based multi-attribute terrain classification approach to more conventional data capture. Having reduced landslide risk associated with much of the registered man-made slope features in the Territory, attention transferred to landslide hazards and instability on natural terrain. The 2400 natural terrain landslides on Lantau in June 2008 reinforced the need for study and mitigation. Many of the early Natural Terrain Hazard Studies in the mid-2000s and the 1963-based relict landslide mapping in the ENTLI in 2006-08 further confirmed the first API-based Site Histories in 1978 revealing old anthropogenic activities on undeveloped hillsides. Styles & Law (2012) highlighted some features and impacts on slope stability ranging from adverse, benign to beneficial depending on the engineering geological settings.

A shift in policy to remove Registered Disturbed Terrain features from the Catalogue of Slopes, coupled with a growing acceptance of the need to integrate old anthropogenic features on natural terrain led to a Hillside Pocket (HP) approach being included in Natural Terrain Hazard Assessment with the revision of GEO 138 (Ho & Roberts, 2016). Inventory of anthropogenic features in NTHA provided a potential method of applying the HP-Pocket approach in a systematic manner. Digital methods enabled by airborne LiDAR integrated with API and field reconnaissance became a pragmatic method for mapping and identification of adverse settings.

Parry & Jonas (2007) discussed the use of LiDAR pilot study work for landslide hazard assessment in Hong Kong. With the first Territory-wide airborne Light Detection and Ranging (LiDAR) survey in 2010 (Lai et al, 2012) digital data became readily available for NTHS and streamlined systematic site characterization. Opportunities for automated mapping however, were limited by the restricted ability to process and manipulate very large data sets.

Application of LiDAR-derived DEM-based terrain classification has been discussed by others in terms of different data processing methodologies. Sas et al. (2012) described the identification of old agricultural terraces using Topographic Position Index (TPI) applied to LiDAR-derived Digital Elevation Models (DEM). Tam et al. (2017) integrated TPI and slope gradient and morphological data in GIS for automated geomorphological mapping in an Automated Integrated Mapping System (AIMS).

With the ever-improving ability for hi-resolution LiDAR penetration of surface vegetation, detailed ground information can be captured as point clouds. High resolution capture and processing enable quality DEMs. Many approaches are available given advances in software and large data management. The DEM enable indirect mapping in software such as Geographic Information System (GIS) with derivation of topographic data of slope angle, aspect and detection of landform changes and man-made features.

With the improvement in LiDAR data resolution reflected in the 2020 Territory-wide survey, advances in data collection techniques coupled with processing enable a range of presentations. The concept of automated DEM-based terrain classification can be applied to the systematic identification and characterization of anthropogenic features of different size and origins. Classification of man-made features is important in assessing the potentially “adverse” Hillside Pocket scenarios during NTHS and join the five hazards (OHL, CDF, RF, BF & DS) for consideration (Ho and Roberts, 2016).

2 Methodology

2.1 Source of data

The most recent Territory-wide aerial LiDAR survey was conducted from December 2019 to February 2020 by the GEO (Wong, 2021) to obtain an airborne-LiDAR point cloud dataset. Processed ground return LiDAR data was used to generate high resolution DEM for the site. DEM can be interpolated in ArcGIS Desktop 10 using various spatial interpolation algorithms such as Inverse Distance Weighted (IDW), Triangulated Irregular Network (TIN) and Kriging. TIN model was used which generally provides higher resolution in areas that are highly variable and preserves precision of the input data.

A 0.25-m node distance in relation to the 0.25-m maximum point spacing for the 2020 LiDAR dataset was adopted. The choice of DEM cell size depends on the density of point cloud data and the scale of the study. A finer cell size was adopted in this study in order to identify anthropogenic features which are often around 0.5m in elevation.

2.2 Digital Terrain Mapping

GIS interprets land surface morphology in uniform grid squares, each grid is referred to as a "cell" of a raster surface. In a raster, every cell is given a value. A digital topographic model that stores raster values for terrain elevation is a Digital Terrain Model (DTM). ArcGIS software is capable of harnessing geospatial information of a DTM by mathematical abstraction to produce maps for visualisation, modelling and analysis.

Slope gradient is a major mobilisation factor associated with slope processes. Slope gradient data is a primary input in terrain classification derived from the DEM. Slope parameters are identified by steepness in each cell. In relation to slope raster, the lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. Slope gradient can be combined with morphology and aspect to refine determination.

2.3 Natural Terrain Hazard Assessment

The site is considered as 'densely-used open space' and public waiting area - a Group 3 facility according to GEO Report No, 138 (2nd Ed.) (Ho & Roberts, 2016), and route upgrading will occur as part of the proposed mine cavern enhancement. Information boards and educational facilities will be constructed within and along walkways. The large mine cavern will be used for some educational display and shelter in adverse weather.

The NTHA is predominantly north-facing hillside, with slope gradients exceeding 15° within some 100m upslope from the Caverns. In accordance with GEO Report No. 138 (2nd Ed.) (Ho & Roberts, 2016), the guidelines for "Inclusion" and further screening in respect of natural terrain hazards are fulfilled.

3 Applications in Lin Ma Hang

3.1 NTHS in Lin Ma Hang

The Natural Terrain Hazard Study Area (NTHSA) is quasi-natural hillside, predominantly underlain by coarse ash crystal tuff of the Tai Mo Shan Formation. Desk study involving a review of elevation data

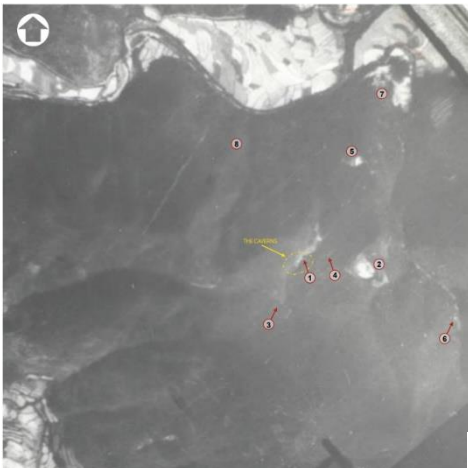

Plate 1: Aerial photograph in 1924. The cavern atrium, tailings dumps, open cast and numerous shafts and remnants of old terraces are evident.

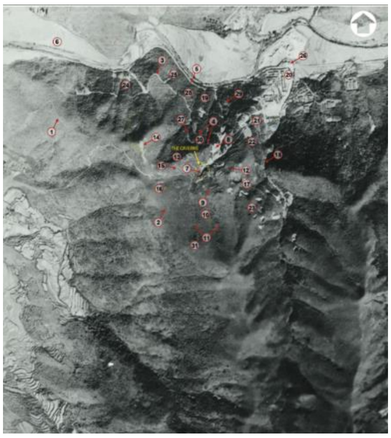

Plate 2: Aerial photograph in 1945. The cavern atrium, many tailings' deposits, shafts, mine workings, military trenches and associated activities occur.

Plate 3: Aerial photograph in 1986. The last year that most of the old workings and remnants of terraces are evident before being masked by vegetation.

and Aerial Photograph Interpretation (API) reveals extensive evidence of old anthropogenic activities within the terrain.

The “conceptual” geomorphological model is based on detailed API integrated with the 2010 and 2020 LiDAR and field reconnaissance as part of the traditional NTHA approach. As the information collection developed, the need for a more comprehensive systematic approach to better classify the terrain model was necessary. Due to the diversity and quantity of the anthropogenic features present, an automated approach was explored. The 1924 (Plate 1), 1945 (Plate 2) and 1986 (Plate 3) aerial photographs show the diverse range of anthropogenic features. In 1986 in particular, areas of bedrock, drainage lines, and zones of colluvial deposition are evident. After 1986 the NTHA becomes progressively more densely vegetated “quasi” natural terrain. The area largely consists of the moderately steep north-facing triangular-shaped hillside catchment, maximum elevation +330mPD, with a small section of southeast-facing open hillside catchment on the upper terrain, rising to +220mPD. A circular basin-like catchment is northeast of the mine. The lower sections of the three catchments meet along an east-west trending incised valley at about +185mPD. The mine atrium is at the toe. From the early 1990s, the ground surface, and with it most evidence of the past mine activity, has been almost completely obscured by the ever-increasing density of vegetation. Recent aerial LiDAR surveys in 2010, and 2020 in particular, has enabled improved systematic characterization of the terrain surface revealing the morphology of the quasi-natural ground surface. Field mapping was in July to August 2021 to verify API, LiDAR and desk study findings, and determine the geological, geomorphological and hydrological conditions. Field work focused on mapping the regolith, landslide features, topographic depressions, drainage lines, prominent rock outcrop, boulders, water inflow, traces of seepage and the extensive impacts of mining related and other anthropogenic activity. The overall geomorphological characteristics of the mine are consistent with those identified in API integrated with the 2020 LiDAR data.

3.2 Digital Terrain Mapping in Lin Ma Hang

Utilizing the DTM patterns derived from LiDAR, Hillshade models are derived (Figure 2), including slope angle, morphology, drainage patterns and catchment zones. These data layers form the foundation of the ground model for terrain classification, as well as the broader geomorphological assessment. The concept of digital terrain mapping system can be illustrated by highlighting features in Lin Ma Hang using GIS related tools for automated spatial analysis.

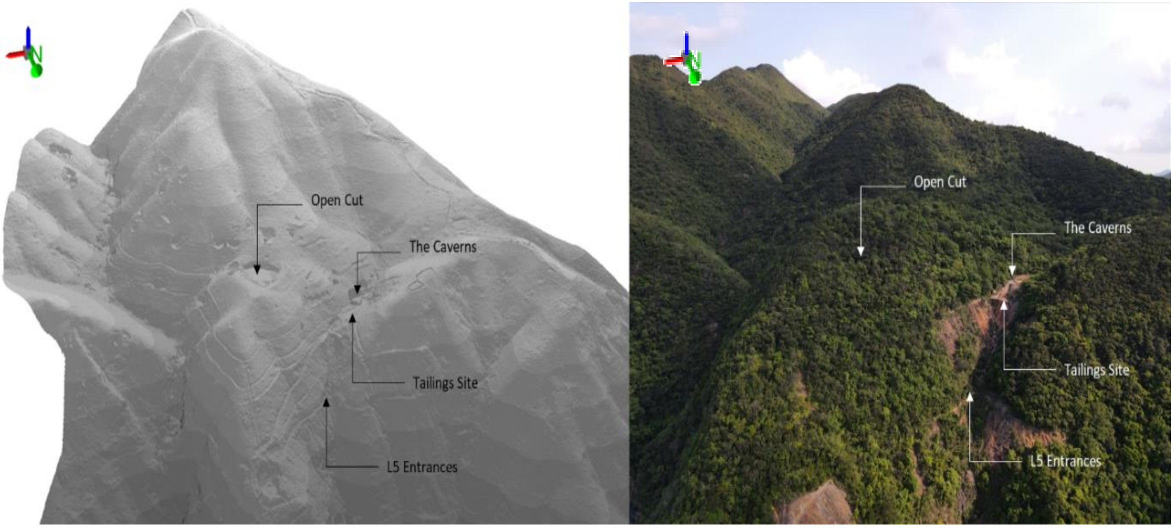

Figure 2: Hillshade model derived from 2020 LiDAR. Numerous platforms, terraces, tailings/spoil deposits, excavations, adits, shafts, military trenches, pathway networks and slope failure.

The first aspect is break-in-slope (BiS). From the DTM, slopes are represented by percentage rise. To identify breaks-in-slope, percentage change between adjacent slope planes are observed. The concept of the tool is to distinguish conditions where adjacent slope planes are at least a 70% change to produce breaks-in-slope on the raster surface. The tool is based on the [SLOPE (Spatial Analyst)] geoprocessing tool modelled in ArcGIS Pro. Slope gradient of the DTM is calculated in terms of percentage rise. Where rise equals run, the percentage would be 100%; situations greater than a 45-degree slope will be greater than 100%; and the percentage decreases as the slope flattens. A slope raster is formed in the same extent as the original DTM. Where the percentage rise is larger than 70%, the raster will flag to indicate BiS. This results in a raster with binary values: 1 is BiS; 0 is not. To optimise visualisation, the results can be modified to show only BiS (value: 1). An extract of the outcome is illustrated against the hillshade (Figure 3) to verify the accuracy of the result. Site reconnaissance was conducted to identify BiS and results were documented in Figure 3b. A comparison of the same extent against the BiS tool results (image in Figure 3a) suggests that the tool produces comparable, or finer detail.

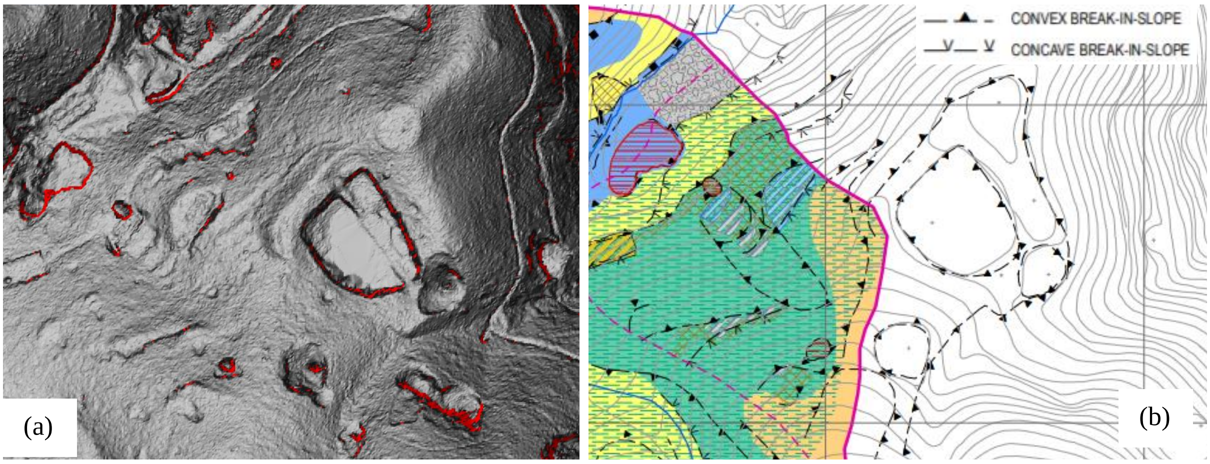

Figure 3a & b: Comparative analysis of BiS detection. a. BiS identified by BiS tool based on 2020 LiDAR data; b. BiS identified in site reconnaissance.

The second feature is shaft detection. Site reconnaissance identified shafts on some terrain mostly hidden by tree canopy. These shafts are generally shallow (~2m) with wide opening; or deep (~10m) with small openings. The study recognised them as historical shafts for mines or subsidence sinks, some possibly from collapsed mine roof or leads. When viewed with Hillshade, the shafts are easily visible by eye. However, the output is in raster graphics that displays a 3D representation of the shafts by shaded relief. In further analysis, separate layers will be exported to depict the outline of the shafts. A tool is developed to outline these shaft features in the terrain. Naturally, each cell in the DTM raster has 8 neighbouring cells. Based on the gridded terrain, the tool identifies the elevation value of each adjacent cell. Once adjacent cells are identified, the corresponding elevation of the middle cell is compared against that of all neighbours. "Sinks" are identified by digitally searching through every cell of the DTM for ones where no neighbouring cells have lower elevation. A smoother new surface raster with no sink is created.

This new surface is envisaged as a piece of cloth draped over the terrain. This surface will have artificially removed topographic features such as subsidence sinkholes and extrapolate them into a smooth facade. The elevation value of the original DTM (representation of the actual landform) will be subtracted by that of the smooth surface. By doing so, not only can sinks be identified, the subtraction also produces a difference in elevation between the 2 surfaces and yields the depth. The tool is based on the [FILL (Spatial Analyst)] geoprocessing tool modelled in ArcGIS Pro. The original DTM is filled. An algorithm was used to locate and fill or remove all depressions or sinks in the DEM, where there is no flow from one cell to another within a conceptual hydrological system. The DTM surface is processed such that any sinks or peaks are removed by iteration until the surface is smoothed. This tool acts as a first-pass to identify shafts in which precision can be adjusted to fit the uniqueness of each terrain. One of our models is shown in Figure 4.

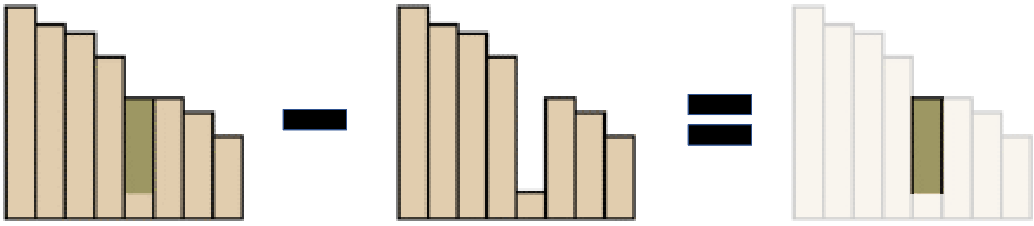

Figure 4: Sink and peak detection

Cell values of the filled-DTM are compared against the original DTM on a cell-by-cell basis. A map algebra will calculate the difference between the filled and original DTM to find areas were fill occurred, by how much, and which should correspond to locations and depth of these sinks. The result of the tool is a raster registered with attribute indicating the depth (Figure 5). The tool result is verified against the Hillshade. Key sinks and depressions are outlined to reveal some very fine detail including depth.

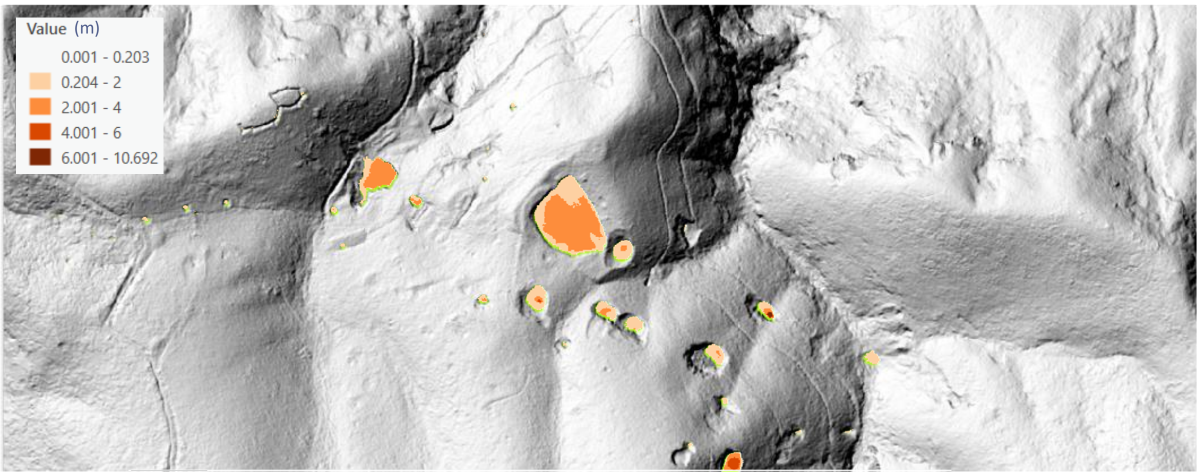

Figure 5: Depth analysis of sinks and excavations, only those sinks that are defined by the input parameters are shown.

The third feature addresses traces of other anthropogenic activity that are apparent based on slope gradient. For example, slopes with gradient more than 5 but less than 60 degrees could be conceived as natural terrain and quasi-natural terrain; or less than 5 degrees, as platforms. Similar to the BiS tool, a procedure is formulated based on the [Slope (Spatial Analyst)] geoprocessing tool in ArcGIS Pro. Instead of the percentage rise, slope angle in degree is calculated from the DTM by the steepness of the elevation value of the raster: the lower the flatter, and vice versa. A customised range of slope angle is then set to display potentially corresponding anthropogenic features in map form. A plate overlaying the tool result on the terrain is verified against photographs in site reconnaissance (Figure 6).

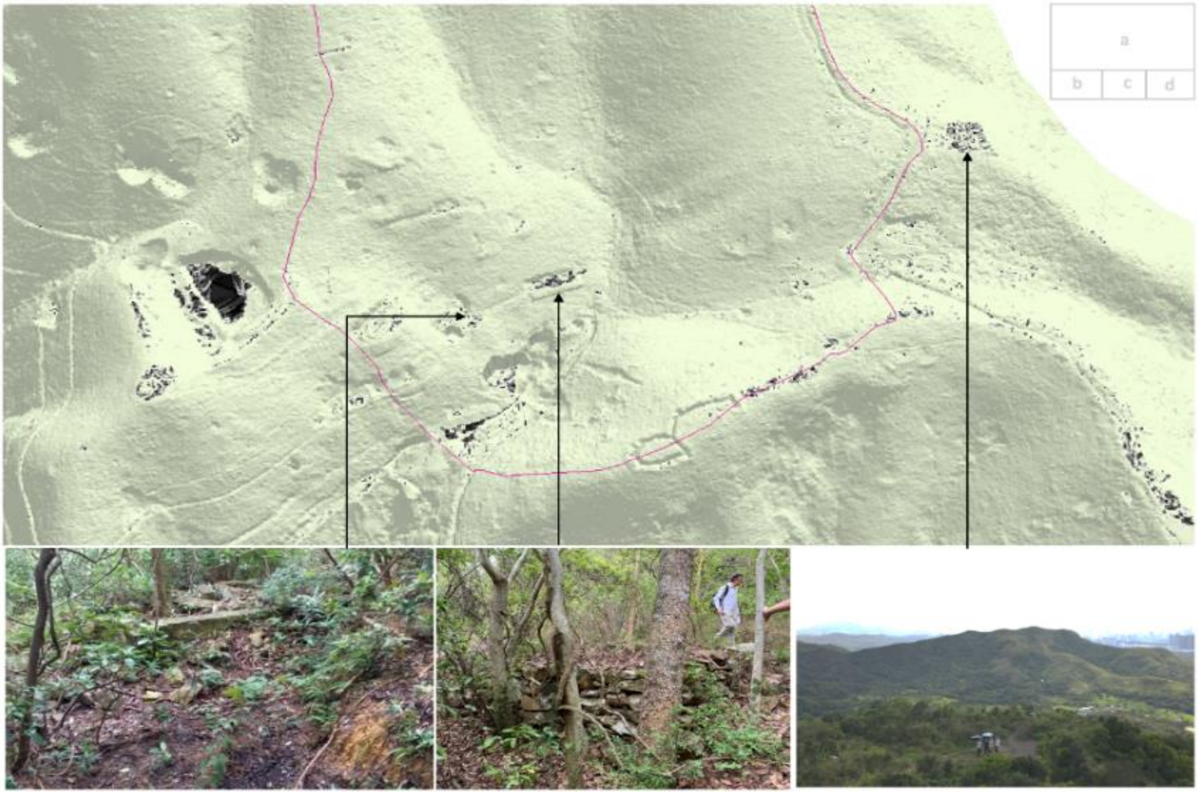

Figure 6: Site verification of the 'platform' features. a. Platform features identified by 'Automated Spatial Analysis Approach' in black clusters; b. Platform with building foundation; c. Rubble wall platform; d. Helicopter pad.

3.3 Classification of Anthropogenic Features

Extensive evidence of anthropogenic activities occurs within the NTHSA. These include:

a) remnants of earthen-step and rubble wall terraces associated with past cycles of old agricultural activity;
b) excavations related to the mine cavern, shafts, adits;
c) deposits of spoil/ tailings;
d) cut and fill slopes associated with mining activities;
e) military trenches and platforms;
f) cut platforms associated with other military security activity; and
g) footpaths and other man-made cuts and channels.

The environs of the mine have been extensively disturbed by mining and military activity with numerous anthropogenic features identified through API integrated with 2020 LiDAR and field mapping.

There is also evidence of older extensive remnants of earthen-step form agriculture and some rubble terraces. Some of these old anthropogenic features resemble landslide scars and tension crack-like breaks-in-slope which in API, and sometimes in the field, are difficult to distinguish. According to Styles & Law (2012) similar features are quite common on natural terrain in Hong Kong and need to be considered on a case-by-case basis. The impacts on slope stability may be beneficial, benign or adverse depending on the geomorphological setting.

According to the observations from the API, the majority of the hillsides near the mine have been disturbed by the anthropogenic activity in the past with impacts on the current landforms creating much "quasi-natural" terrain. The main types of anthropogenic activity are based on the observations from the API integrated with 2010 and 2020 LiDAR and reconnaissance field mapping. There is much evidence of Hillside Pocket (HP) Settings GEO Report 138 (GEO, 2016). The anthropogenic classification provides an inventory of the main forms encountered in the area (Table 1 & Table 2). The classification scheme arises from Styles & Law (2012). The classification will be further refined with ongoing field work related to the project GI. Some of these features are described below based on information collected through the automated tools integrated with API and field mapping.

Table 1: Observed anthropogenic features

i. A rock adit tunnel southeast of the mine (Plate 4) the portal cutting into a northwest facing natural slope. The adit leads to two dead-ends some 16m long. Three stepped cut platforms, each of them around 1m high, are adjacent to the portal whilst local subsidence is noted near the platforms. The steep portal cut is indicated by slope gradient >60°.
ii. A rock cut vertical shaft (Plate 5) to the southwest of the atrium, adjacent to the man-made channel about 2m by 2m opening and some 8m in depth. The shaft is connected to an adit inside the mine.
iii. A platform with a rubble wall about 1m high and 18m long was identified adjacent to a drainage line. Another cut platform, about 2.5m high with remnants of a pad foundation was identified slightly northeast of the stepped platform at the eastern edge of the site. The terrain is marked as being <20m in length and with a gradient of <5°.
iv. Remnants of earthen step-form terraces and old rubble wall terraces on the planar hillslope between drainage lines were observed in API and were confirmed during field mapping. The terrain is characterised by remnants of a contour-like stepped profile formed by very old terraces. The platforms are small and linear, and are about 0.5m high and less than 2m wide.
v. A military trench system occurs at the crest of slope north of the mine. The trench is about 0.5m wide and 1.5m deep circular in nature and is clearly evident in 1945 aerial photographs and the 2020 LiDAR. Further trenches or cuts about 0.5m wide and 0.3m deep were recognised downslope and may be associated with military activity. The small scale of the cut, <5m, and shallow depth mean it is difficult to detect in automated tools. The steep cut slopes, > 60°, are easily identifiable as breaks-in-slope.
vi. Man-made feature no. 3NE-A/C78 is a concave depression characterised by a landslide-like scarp break-in-slope probably associated with man-made cutting and disturbance.
vii. Three old potential water storage excavations identified near the mine. Two are adjacent to a drainage line whilst one is in a rubble wall platform.
viii. A U-channel at the edge of the tailings site. At present, water flows from the man-made channel into the mine and via an adit towards the tailings site. Flows are collected by an old U-channel on the tailings before discharging into the natural drainage line to the northeast.
ix. Barbed wire traversing the hillslope southwest of the mine was apparent in the API. During the field mapping, remnants of the barbed wire and associated gates are scattered around the terrain generally consistent with the API observations.

Plate 4: Adit identified by LiDAR integrated with API and field mapping.

Plate 5: Shaft identified by LiDAR integrated with API and field mapping.

The automated spatial analysis tool is able to identify most features and forms an initial layer for terrain mapping analysis. Remnants of rubble wall/concrete platforms with building ruins, tailings/ spoil deposits (Plate 6), mine adits and shafts, open-cuts (Plate 7), water tanks and other workings, together with military trenches and associated activity, fortuitous prospecting, as well as very old remnants of agricultural practices with rubble walls and earthen step-form terraces are all observed. The definitions and general descriptions of anthropogenic features in the Lin Ma Hang area are contained in Table 2. The classification forms part of an overall 80 class system for the territory (Styles & Pook, in prep.).

Plate 6: Tailings / spoil deposits identified by LiDAR integrated with API and field mapping.

Plate 7: Open cut identified by LiDAR integrated with API and field mapping.

These are further subdivided based on dimensions to enable a systematic assessment of the hazard susceptibility of various features within the natural terrain.

Table 2: Anthropogenic features identified at Lin Ma Hang

Class	Type / Nature / Description (after Styles & Law, 2012)	
A – Agricultural terraces & associated activities	A1 – Old Remnants walled terraces	Presence of wall e.g., stone, rubble wall agricultural terraces. Previously formed for cultivation
	A2 – Old walled terraces (herringbone)	Presence of walls e.g., stone, rubble in herringbone pattern - formed for cultivation. Usually associated with tea production
	A3 – Old earthen step form terraces	No walls Series of small cut slopes usually on steep slopes on deeply weathered terrain Previously formed for cultivation
	A4 – Remnants of old step form terraces	No walls Intermittent remnants of eroded & degraded terraces
	A9 – Old ruins / rubble wall terraces / undetermined	Presence of ordered layout of very old structures or rubble terraces. May be single layer or intermittent parts of ruins
B – Military & associated activities (cut & fill generally associated)	B1 – trenches	A narrow, linear excavation used in military defences
	B2 – Foxholes, some trenches & other minor excavations	A shallow pit or shallow excavation dug by military for defensive refuge & as firing locations
	B5 - Battlefield / Conflict Zone (general locations)	An area of previous military combat.
	B7 – Undetermined military disturbance	Disturbance caused by unknown military activities
	B9 – Observation Post	Military or Police look out location
	Disturbed area caused by the processes of extracting ore or minerals, adits, platforms, spoil & tailings deposits	
C1 – Mining Large Scale Mechanised Industrial	1 – Tailings/Spoil (Fill)	
	2 – Cut	
	3 – Retaining Structure	
	4 – Retaining Structure – Fill Platform	
C2 - Prospecting & opportunistic mining (labour intensive)	Disturbance caused by labour intensive prospecting - usually single man operations	
I – Other man-made disturbance (cut and fill generally associated)	I1 – Cut off drain – U channel	
	I2 – Pipeline	
	I4 – Paths, tracks & roads	
K – Registered cut & fill features	K1 - Registered Retaining Wall Feature	
	K2 - Registered Cut slope Feature	
	K3 - Registered Fill slope Feature	

3.4 Hazard Assessment

By applying an automated spatial analysis tool approach to identify anthropogenic features, such as shafts or breaks-in-slope, it is possible to overlay these with various data layers for hazard analysis. The first stage, in an area so densely affected by anthropogenic features, is inventory of occurrence, and then to determine where a hillside pocket scenario is susceptible to an "adverse" geomorphological scenario or setting (Figure 7). By identifying drainage lines, catchment basins, clusters of disturbance or fill deposits with an appropriate buffer, a data layer of potential adverse anthropogenic features can be obtained based on the dimensions and nature of the anthropogenic feature using a fast and efficient automated system. This provides a platform for more detailed analysis through traditional methods including site verification. Use of GIS tools to detect and determine the breaks-in-slope and shafts/ excavations and other features is vital. Part of the scope of the project was to determine the extent and layout of shafts, adits and related excavated features that could potentially pose a hazard to the public after the enhancement scheme.

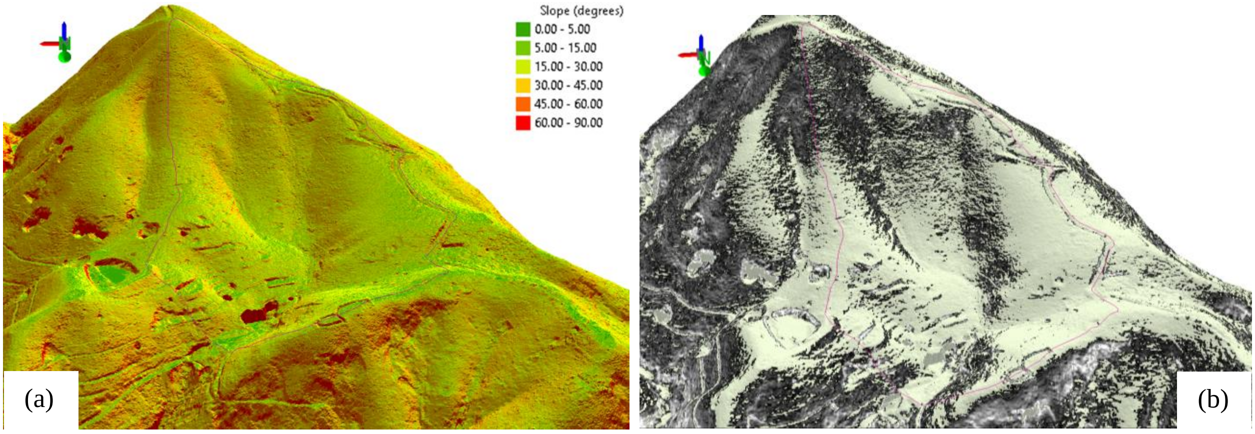

Figure 7: (a) Slope angle map derived from 2020 LiDAR-based DTM – anthropogenic features such as caverns and open cut are clearly visible, (b) Terrain surface heterogeneity.

3.5 Field Verification and Discussion

A classification system for anthropogenic features is being developed with reference to the diversity of features associated with the mine and hillside terrain. The automated spatial analysis tools applied to date have had initial success, with further refinement and applications likely. The LiDAR data and field mapping observations were generally reflected in the output. The advantages are that an initial shape file with key dimensions is derived from the terrain features which can aid in early hazard analysis. These can be verified and modified from site observations to form an integrated ground model. The approach provides an important first step in screening for features that require investigation.

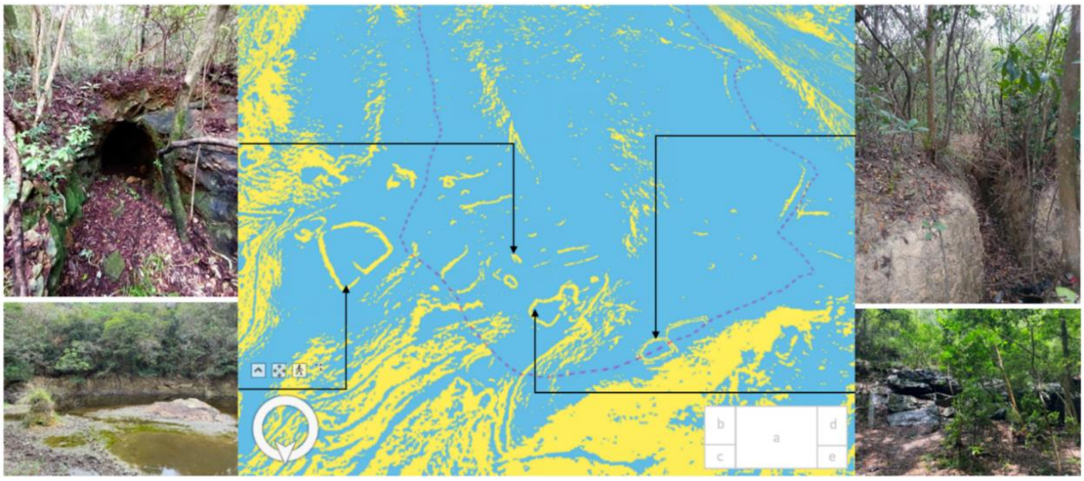

Figure 8: Site verification of 'break-in-slope (BiS)' features identified by automated spatial analysis approach – remnants of terracing and platforms are visible

The principle of utilizing automated spatial analysis tools is to define Terrain Unit Elements (TUE) based on extent and position relative to contours (Table 3). These are then subdivided by gradient of slope and classified according to morphology as planar, concave or convex. Breaks-in-slope are identified and differentiated as convex or concave to distinguish areas of homogeneity (Figure 8). Vertical features can be further classified based on depth/ height. This initial stage of automated spatial analysis tools is for terrain inventory classification. Derivative maps can be produced using a variety of buffer and overlay functions to display the data for specific requirements, such as proximity to natural drainage lines; man-made drainage lines; slopes >30 degrees in gradient and 3m in height/depth; and platforms >3m in height. As an example, the large anthropogenic fill features are shown in relation to drainage lines to determine the potential for adverse hillside pocket scenarios in NTHA of the quasi-natural terrain.

Table 3: Terrain Unit Element (TUE) Classification

TUE	**Attribute**			**Possible Anthropogenic Feature**
	Length	Slope Gradient	Depth	
Normal to contour & planar	<20m	<5°	-	Platforms
Normal to contour & planar	<20m	>60°	-	Masonry walls & steep cuts
Normal to contour	>20m & <60m	>30° & <60°	-	Large tailings & spoil dumps
Normal to contour	<20m	>30° & <60°	-	Smaller tailings, spoil dumps & fill slopes
Normal to contour	<5m	>60°	-	Military trenches
Any location	<10m	-	>3m	Vertical shafts
Any location	>40m	-	>3m	Open cut

4 Conclusion & Further Studies

Well established principles of API 4D analysis integrated with LiDAR and field verification underpin an automated spatial analysis tool approach. Techniques based on digital data inputs of slope gradient, size, shape, extent and aspect of features to help delineate anthropogenic activity on the quasi-natural landscape. With the aid of digital classification, potentially adverse Hillside Pocket settings can be systematically highlighted for field review and modelling in Natural Terrain Hazard Assessment.

The success of automated spatial analysis tools is tempered by the knowledge that to get the most accurate result for feature location, such as shaft identification, scripting and machine learning techniques are required. Flow direction tools can be further explored as an option where Terrain Unit Element (TUE) lengths are normal to the contours. Further work will be conducted on ways to enable extraction of BiS and to convert raster results into line features. Throughout the process the need to build a statistical model to determine the geomorphometric characteristics of a large number of anthropogenic features is recognised to refine the parameters for identification in the LiDAR derived DTM.

Further works will aim to incorporate a spatial tool kit approach for anthropogenic features into an automated systematic terrain classification for NTHS.

5 Declarations

5.1 Acknowledgements

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5.2 Publisher's Note

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