The Possibility of Using Terrestrial-Based Ground Penetrating Radar (GPR) Technology for Supplying 3rd Dimension Information for a Search and Recovery Mission for Landslide Victims

Halim, N. Z. A.,[1,2*] Abdullah, N.,[2] Ghazali, M. D.[3] and Hassan, H.[1]
[1]Department of Survey and Mapping Malaysia (JUPEM), Jalan Sultan Yahya Petra, 50578 Kuala Lumpur, Malaysia, E-mail: nurzurairah@jupem.gov.my*
[2]Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, 86400 Batu Pahat, Johor, Malaysia
[3]College of Built Environment, Universiti Teknologi MARA Perlis Branch, 02600 Arau, Perlis, Malaysia
Corresponding Author

DOI: https://doi.org/10.52939/ijg.v19i5.2669

Abstract
This paper highlights the possibility of using terrestrial-based GPR to provide third dimension (depth) information to facilitate a landslide search and recovery (SAR) mission in Malaysia. The study was based on an actual use case during the 2022 landslide tragedy that occurred at the Father's Organic Farm, Batang Kali. Two sets of MALA RAMAC X3M with shielded antennas (250MHz and 500 MHz) were used to survey a 1m x 1m profile interval at a 30m x 20m and 8m x 6m grid areas in Sector B on the 18th and 19th December 2022. Grid line profiles 2211-A, 2212-A, and 2213-A detected by the 250MHz antenna showed suspicious reflection patterns. The pattern's amplitude contrast in relation to the soil background and the consistency with the average Malaysian adult's stature was considered fit as the most likely location of landslide victims. The locations of the reflection were viewed with greater accuracy and clarity utilising time slice y-cut on 3D processing in the Reflex3DScan ReflexW module. On 21st December 2022, the SAR team recovered a victim and his two dogs near the suspected GPR line profiles at sector B. The suspected GPR signal reflections corroborated with the proximity where the victim was found according to the special SAR victim location map published by SAR authorities. Since access to ground zero post-excavation was restricted, on-site validation of the suspected profiles was not possible. Nonetheless, because hyperbolas were detectable at a lower frequency with a maximum depth of around 8m, this paper concludes that using terrestrial-based GPR as a SAR alternative for buried landslide victims is still feasible. The challenge would be having a skilled operator to detect a hyperbola or abnormality in a time-critical scenario. The study also concluded that terrestrial-based GPR would, at the very least, provide first responders with situational awareness by narrowing down the SAR potential locations, excavation depths and reducing time for searching and recovering victims, as concurred by the Batang Kali SAR team.

Keywords: 3D Visualisation, Ground Penetrating Radar (GPR), Malaysia, Search and Rescue (SAR) Mission

1. Introduction

On 16th December 2022, Malaysians were shocked by the news of a landslide in a campsite near Batang Kali, Selangor. It was the second most horrific landslide tragedy in Malaysia, with the first being the collapse of the Highland Towers in 1993 which caused 48 lives. According to the report by Radhi et al., [1], around 450,000 m3 (16 million cu ft) of soil were displaced, causing a landslide that submerged campsites on the organic farm known as Father's Organic Farm, where the tragedy occurred. The catastrophe entombed 92 individuals beneath the collapsed slope, most of whom were campers from the farm. There were 31 fatalities, 61 rescues, and 8 individuals who required hospitalisation.

The Department of Survey and Mapping Malaysia (JUPEM) was one of the government agencies that provided the geospatial data required to facilitate the search and rescue (SAR) mission at the Batang Kali campsite [2]. The goal of SAR is to locate, stabilise and extract individuals in distress. Lack of communications and data relay hampers practical SAR activities.

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) |

In the past, JUPEM has assisted the National Security Council (MKN) and the National Disaster Management Agency (NADMA) in administering national emergencies and crises that included floods [3], earthquakes [4], landslides [5], and even pollution [6]. The lessons learned from these events allowed JUPEM to construct the *Peraturan Tetap Operasi* (PTO) manuals, which included 10 different natural disaster scenarios and were released on 22nd September 2020 [7]. The PTO incorporates methods for JUPEM to organise its internal operations of creating various geospatial data so that relevant parties can optimise the data and expertise available in JUPEM for informed decision-making, particularly during SAR operations.

Aside from preparing risk maps and other forms of geospatial data, terrestrial-based Ground Penetrating Radar (GPR) instruments were deployed by JUPEM to facilitate the SAR mission team at the Batang Kali campsite. Search and recovery (which is more suitable in the Batang Kali use case) has been a niche application for GPR and has frequently been used in tragedy areas to separate locations of interest for the recovery of human remains [8]. Interestingly, even though around 40 landslides have occurred in Malaysia over the past two decades [5], and the fact that GPR technology has been used by JUPEM for subsurface utility mapping since 2006 [9], GPR technology was only recently opted for SAR missions during the Batang Kali landslide incident. Therefore, this paper highlights the possibility of using terrestrial-based GPR technology to provide third dimension (depth) information to facilitate a SAR mission in Malaysia, specifically for landslide victims. JUPEM's limitations in disseminating spatial data to significant parties for this particular disaster will not be explored in this study, but a similar experience with a different sort of disaster can be found in Hassan et al., [10]. Section 2 explains why GPR is considered a better option for SAR missions. Section 3 describes the terrestrial-based GPR methodology used in the Batang Kali SAR mission case and the limitation of the terrain. Section 4 will then highlight the result and analysis of the GPR scanning, and lastly, Section 5 will discuss the challenges and conclude the GPR actual use case during the Batang Kali landslide’s SAR mission. Since GPR was never applied for SAR missions in Malaysia [11], the lessons learnt from the experience are also highlighted accordingly in each section.

2. Why GPR Technology?

Subsurface imaging can be done with non-destructive GPR, which transmits electromagnetic waves into the subsurface and records their reflections [12]. Typically, the images of GPR are used to depict the reflectivity of a subsurface item and spatial location. Terrestrial-based GPR can be utilised to investigate underlying objects up to tens of metres deep (depth in three-dimensional data) [13]. The technology can find landmines, locate subsurface utilities, and evaluate bridges, pavements, tunnels, and structures [14]. Buried feature information from 2D radargrams can also be retrieved with unique algorithms, as Hu et al., [12], Hu et al., [14] and Akbari et al., [15] have demonstrated. Hu et al., [14], for example, developed a unique algorithm that enables the GPR images to locate and detect automatically and characterise lean-to-collapse cavities submerged in disaster wreckages to aid search and rescue operations.

In a typical SAR mission for a collapsed structure, the first responders are generally required to manually search for victims between gaps and holes within the collapsed structure caused by an earthquake or landslide. The third dimension or depth information of the buried victims is a piece of critical information that provides situation awareness in SAR missions. Sound detection and thermal imaging technologies are examples of human detection techniques. These technologies, however, are unreliable in disaster areas due to their sensitivity to noise and heat sources [16]. In order to locate trapped victims, dogs must be first trained for years at a prohibitive cost [17]. A typical trained dog in a K9 unit can cost as much as RM110,000.00. Furthermore, dust-laden air could impair a trained dog’s sense of smell and inhibit its usefulness. In addition, trained dogs cannot help the search and rescue efforts by providing visual clues or quantitative information like void size and location. GPR’s defining characteristic is its ability to identify new shallow soil alteration conditions induced by soil disturbance and the introduction of foreign material. Consequently, an operator should be able to determine the specific metric grid coordinates, general form, depth, and approximate size of obscured material for a subsurface disturbance. However, success will vary depending on soil conditions [18]. In layman's words, GPR is about efficient search, showing users where to dig. A GPR does not get tired, it does not need silence, and it does not rely line on sight detection. Other types of victim detection techniques used for locating and recovering individuals trapped beneath collapsed structures are explained in Joret et al. [19].

Therefore, given the limitations of existing SAR mission practice, there is an urgent need for innovative ways to rapidly provide quantitative and accurate information regarding voids buried in disaster areas.

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) | © Geoinformatics International

Such information allows rescuers to make informed decision-making and improves first responders' situational awareness, potentially reducing search and rescue duration and increasing victim rescue. According to Lombardi et al., [20], GPR technology has been helpful in SAR operations, whether in urban or rural settings and in searching for human remains or buried evidence. In the past, it was used to search for a snowmobiler that was buried by an avalanche at Spitsbergen [21], accurately locate clandestine graves [22], and also used as a tool in the non-destructive evaluation of structures destroyed by either natural catastrophe such as earthquake, avalanche and mud-slides [8] or manmade disasters such as building or mine collapsing [20]. On the same note, given that the location of the buried victim is vital for a landslide SAR mission, GPR might be regarded as an excellent option for the Batang Kali landslide. In comparison, GPR can estimate features' depth (3D) more precisely and quickly than other geophysical techniques [20]. The other reason is the fact that JUPEM owns two sets of terrestrial-based GPR sensors with varying frequencies that can be utilised and studied for the mission.

3. The Usage of GPR Technology for Batang Kali Landslide SAR Mission

3.1 Site Conditions

The SAR site is located near the Father's Organic Farm in Batang Kali, Selangor, not far from where the landslide occurred at 2°50″N and 102° 9″E. The farm is in close proximity to rugged topography, and the Batang Kali - Genting Highland Road passes directly on top of the hilly terrain. There is also an unnamed creek across the farm that was covered up with soil and landslide debris, as shown in Figure 1.

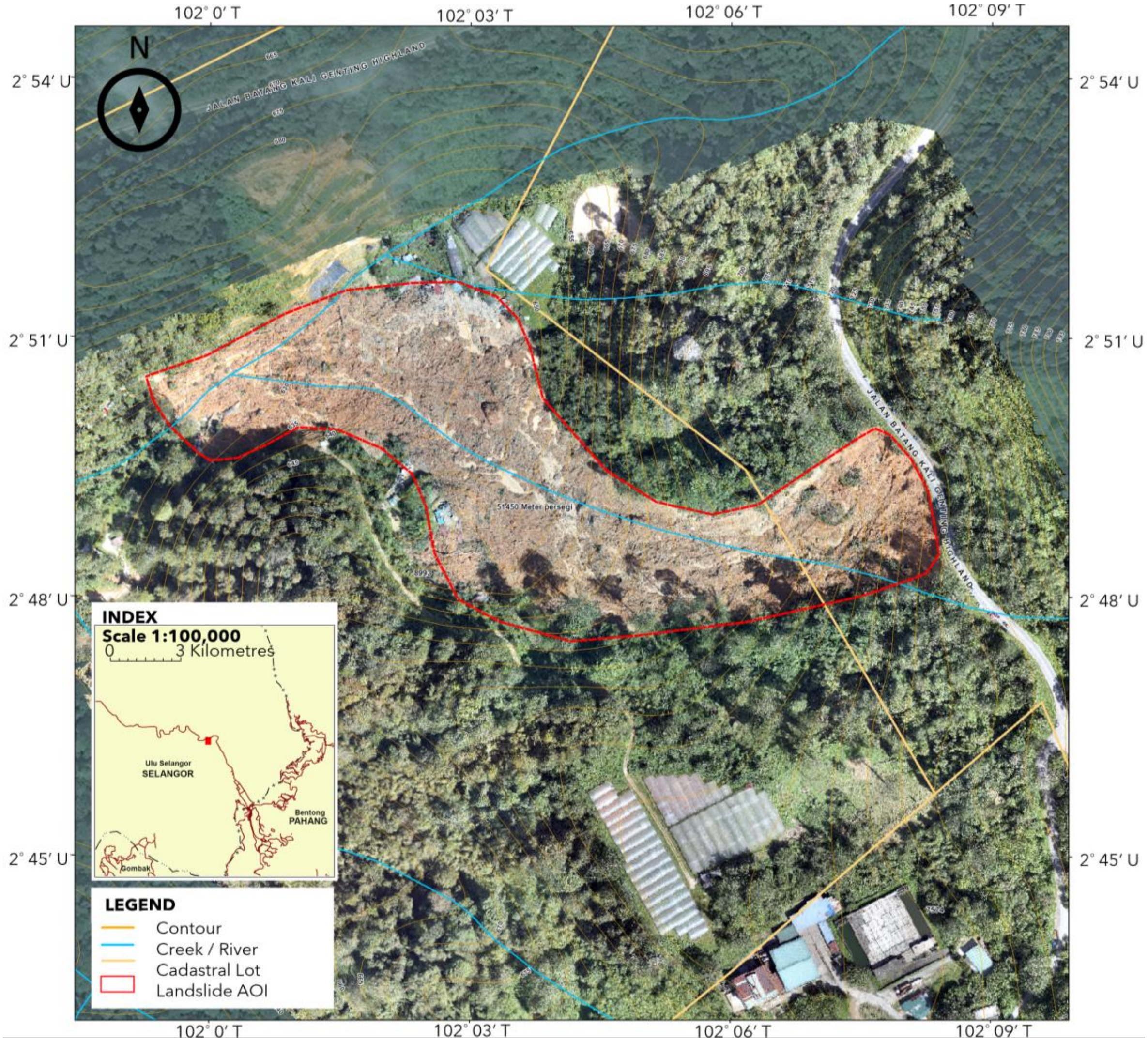


Figure 1: Father's organic farm landslide area of interest

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) |

Several days of rain before and after the incident have also resulted in thick, muddy, and rocky soil conditions in the landslide area. All three campsites (Farmview, Riverview, and Hillview) at the Father's Organic Farm were directly affected by the collapsed slope that created a 30-meter-tall, 1.21-hectare-wide field of debris [23]. The SAR coverage area was slightly larger than 5 ha, making it a very large SAR area to sweep. Consequently, approximately 400 SAR personnel from 15 various government departments were dispatched to assist with rescue work. Initially, 6 trained tracking dogs were utilised for the SAR missions but gradually increased to 11. By the end of the SAR missions, the team was subsequently stretched to include almost 700 rescue personnel and 8 excavators.

3.2 Data Acquisition

A Måla GPR system (MALA RAMAC X3M) was used for the SAR case study mission, and generally, the method was according to Figure 2. The GPR system was procured by JUPEM in 2015 and was calibrated annually in accordance with the utility tool detection procedure guideline prepared by JUPEM [24]. Data acquisition was conducted on the afternoons of 18th and 19th December 2022 under clear skies. The GPR area of interest for scanning (AOI) was determined by the Selangor Fire and Rescue Department (BOMBA) at Sector B (Farmview). Considering the large coverage of the SAR area and the limited number of GPR sets available, the GPR detection measurements were obtained using a 1m x 1m profile interval at a 30m x 20m grid and 8m x 6m area, as shown in Figure 3.

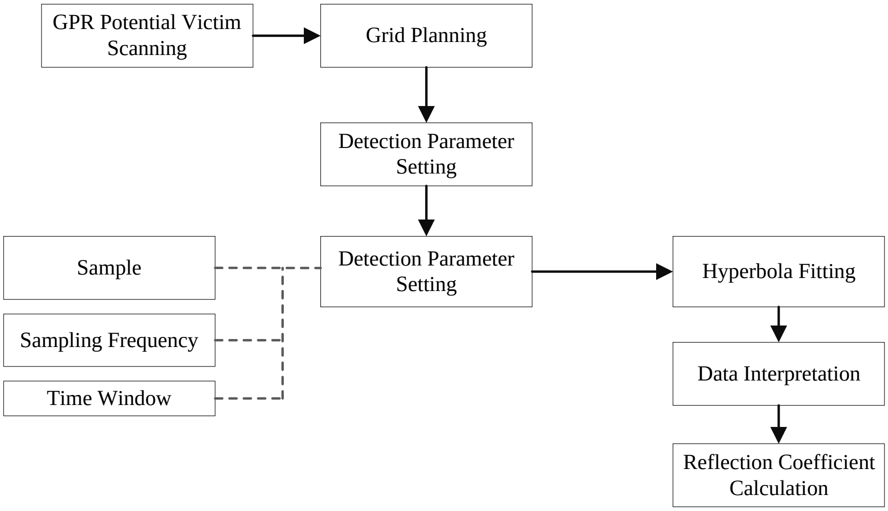


Figure 2: General methodology for GPR potential victim scanning

Figure 3: Potential landslide victim location within the GPR AOI grid

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) |

The situation at ground zero necessitates adaptability despite the fact that, according to Samet et al., [25], a profile interval greater than 1 m could result in inaccurately measured underground features. The rationale of the profile interval was to ensure a continuous mode of overlapping results of the objects under the ground and to avoid voids from occurring during scans. Nevertheless, the profile intervals are still acceptable, considering the intervals are smaller than the estimated average stature of an adult Malaysian male, which according to Deros et al., [26], is 162cm. Other factors that could degrade optimum data quality were considered following the suggestions from Salako et al., [27] for data acquisition. The scannings were done with a shielded antenna of a common-offset measurement, 250MHz, based on the set of parameters as stated in Table 1. GPR is limited by the wavelength, which is used to locate objects accurately in both horizontal as well as vertical planes. When antenna frequency and substrate velocity are known, it is possible to ascertain the medium's wavelength and estimate the vertical resolution as a fraction of its wavelength. Therefore, velocities are resolved first to determine the soil’s true depth at the GPR AOI by applying hyperbola fitting. It was discovered that 0.1000 m/ns is the GPR velocity, and research by Salako et al., [27] indicates that the soil at the Batang Kali landslide can be regarded to have been composed of saturated mixed soil components.

Another challenge on site was, due to the undulating and soft landslip surface surrounding the GPR AOI, plywood was used to level the GPR line scanning, as depicted in Figure 4(a). The strategy was necessary to decrease the frequency of voids during the scanning procedure. However, the use of only plywood was considered impractical, as the scans of the uneven landslide surface revealed voids. Figure 4(b) demonstrates that, as a result of levelling the landslide surface with an excavator, continuous GPR line scanning was enabled, making it much simpler to distinguish between reflections from soil blocks and characteristics of landslide debris or potential victims.

Table 1: GPR-SAR Measurement and Processing Step Parameters

250 MHz	
Measurement Setting	***Parameter***
Antenna Separation	0.31m
Sample	512
Time Window	170.342ns
Sampling Frequency	3005.72MHz
ReflexW	
Process	***Parameter***
Time zero	-7.40749
Dynamic Correction	0.31m
Dewow Filtering	170.342ns
Bandpass Filtering	125-375
Gain Function	2 db/m
Hyperbola Fitting	0.1000m/ns

(a) (b)

Figure 4: Plywood is used to flatten the undulated collapsed surface. (a) The condition of the surface prior to the use of an excavator. (b) Excavator-levelled land results in a more accurate GPR scan

Figure 5: Stakes indicating Possible Victims / Buried Objects Location Based on the Hyperbola Detections

Throughout the scan, the GPR cart was, as possible, being maintained in a straight path, and the screen was observed for the presence of hyperbolas or other abnormalities. In the event that a hyperbola was identified on site, a spike was staked to the ground to roughly indicate a potential SAR excavation area, as shown in Figure 5. After the marking, the scan was continued until a new hyperbola is discovered or the run is completed. Overall, there were 18 hyperbolas identified within the GPR AOI, as shown in Figure 3. The depths of the hyperbola were jotted down and were provided to BOMBA. Radargrams were then post-processed to corroborate the location of the hyperbolas reported on-site. The minimum depth at which the hyperbola was detected was less than 0.4 meters, while the maximum was greater than 4 meters, indicating that the soil is not completely wet and consists of saturated mixed soil components.

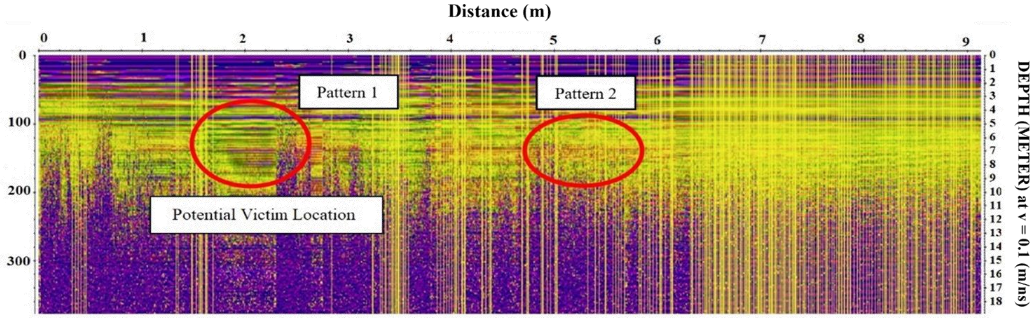
3.3 GPR Processing

Since the obtained raw signal GPR data contains significant noise that can lead to inaccurate data, Reflexw software was used to process the data to gain relevant information and a more distinct hyperbola reflection. Reflexw was used to process raw reflection profiles representing single transect data, delivering depth and distance information. These reflection profiles were all processed with the same parameters and filters, as shown in Table 1. In order to increase the signal-to-noise ratio, the following steps were followed: i) Time zero correction; ii) Dynamic correction; iii) Dewow filtering; iv) Background removal; v) Bandpass filter; vi) Gain functions and vii) Hyperbola filtering. These profiles were then processed again and counter-checked to ensure that gain settings were sufficient for visibility. Other than that, considerations of using GPR for trapped victims as suggested by Cist [8] were considered for interpretation that included i) signal generated by victims; ii) attenuation through the debris pile; iii) external noise; iv) internal noise and v) algorithm performance. The on-site GPR markers and processed dataset (x,y, and z information) of the GPR AOI in Sector B were provided and handed over to the SAR team on 20th December 2022. All GPR information was given to increase SAR mission possibilities.

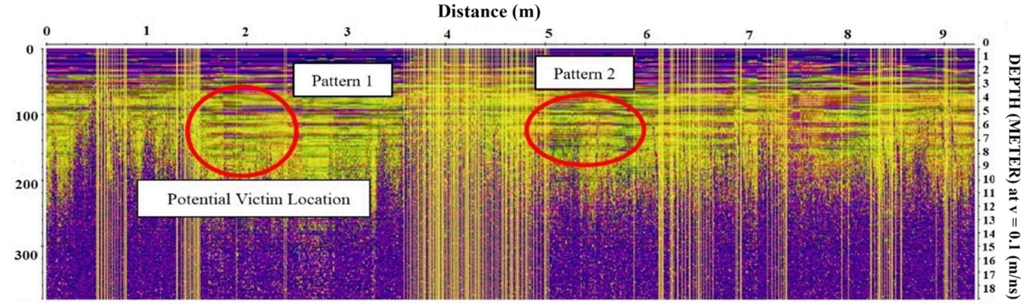
4. Results and Analysis

The GPR profile of the 2D image signal from the 250MHz frequency antenna illustrates the capability of initiating SAR operations with the detection of potential landslide victims to a depth of around 8 metres, as depicted in Figure 6. Even though the acquired GPR signal image has residual noise that is difficult to eradicate, the reflection of the subsurface dielectric contrast is still clearly visible. As depicted in Figure 6, three grid line profiles from the GPR line profile, specifically 2211-A, 2212-A, and 2213-A, exhibit suspicious reflection patterns. The patterns suggested where the possible victim can be detected and recovered in Sector B, at horizontal lines 2211-A, 2212-A, and 2213-A. There are two distinct dielectric contrast reflection patterns, the first being between 1.5 m and 2.5 m horizontally and 7 and 8 metres vertically for all three profile lines, although line 2213-A appears less distinct. A clear reflection of the second pattern is only apparent on profile line 2212-A, which is between 5 and 6 metres horizontally and 7 to 8 metres vertically.

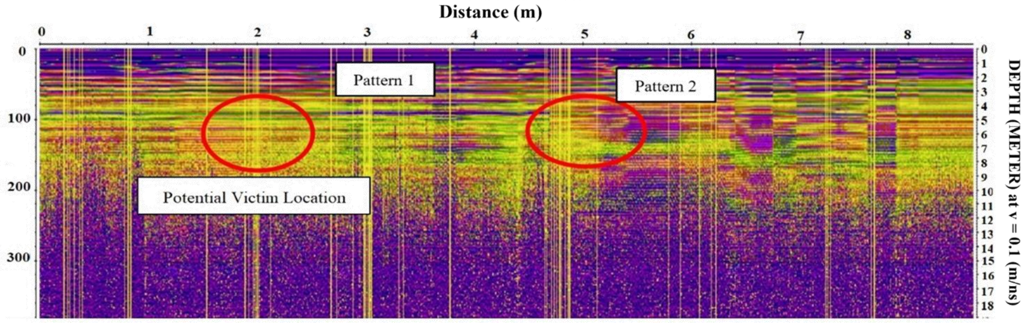
ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) |



(a) Line 2211-A



(b) Line 2212-A



(c) Line 2213-A

Figure 6: A radar image that is believed to depict the area where the possible victim was detected and found in Sector B, at horizontal lines 2211-A, 2212-A, and 2213-A

This pattern seems more divergent since the data processing does not contain a migration procedure; this is done to simplify the process of analysing the GPR signal image by making the reflection appear more distinct. In GPR signal image processing, migration, such as Frequency-Wavenumber (F-K) migration, is conducted to reconstruct the defect's geometry when determining its shape pattern [28]. The reflection coefficient in Table 2 provides a good illustration of the GPR data profile's reflections for identifying buried objects or victims. The reflection coefficient can be described as a function of the radio wave at an angle perpendicular to the velocity boundary between the incident wave and the reflection, as R=(V2-V1)/(V2+V2). The reflection coefficient in pattern 1 suggests that there is a high likelihood of signal reflection, which is most probably triggered by the dielectric contrast of the landslide debris or victim. This is due to the fact that the reflection between profiles 2211-A and 2212-A, considering a grid interval of 1 m, can show the most possible of a potential victim's physique or substantial landslide debris.

The suspected GPR signal reflections were corroborated with the special SAR team's map of the approximate positions of all 31 recovered victims, specifically in Sector B, where a body was found close to profiles 2211-A to 2213-A. The map, which was published on 24th December 2022, is depicted in Figure 7. A landslide victim was successfully recovered with his two dogs in sector B on 21st December 2022 at around 11:00 am [29].

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) |

Table 2: Reflection Coefficient (R) of GPR Signal in Radar Image Sector B for Line A 2211 – 2213

Line 11	***Velocity 1***	***Velocity 2***	***Reflection coefficient***
Pattern 1	0.0794	0.0729	0.042
Pattern 2	0.0810	0.0794	0.040

Line 12	***Velocity 1***	***Velocity 2***	***Reflection coefficient***
Pattern 1	0.0895	0.0797	0.057
Pattern 2	0.0822	0.0754	0.043

Line 13	***Velocity 1***	***Velocity 2***	***Reflection coefficient***
Pattern 1	0.0868	0.0817	0.030
Pattern 2	0.0846	0.0805	0.024

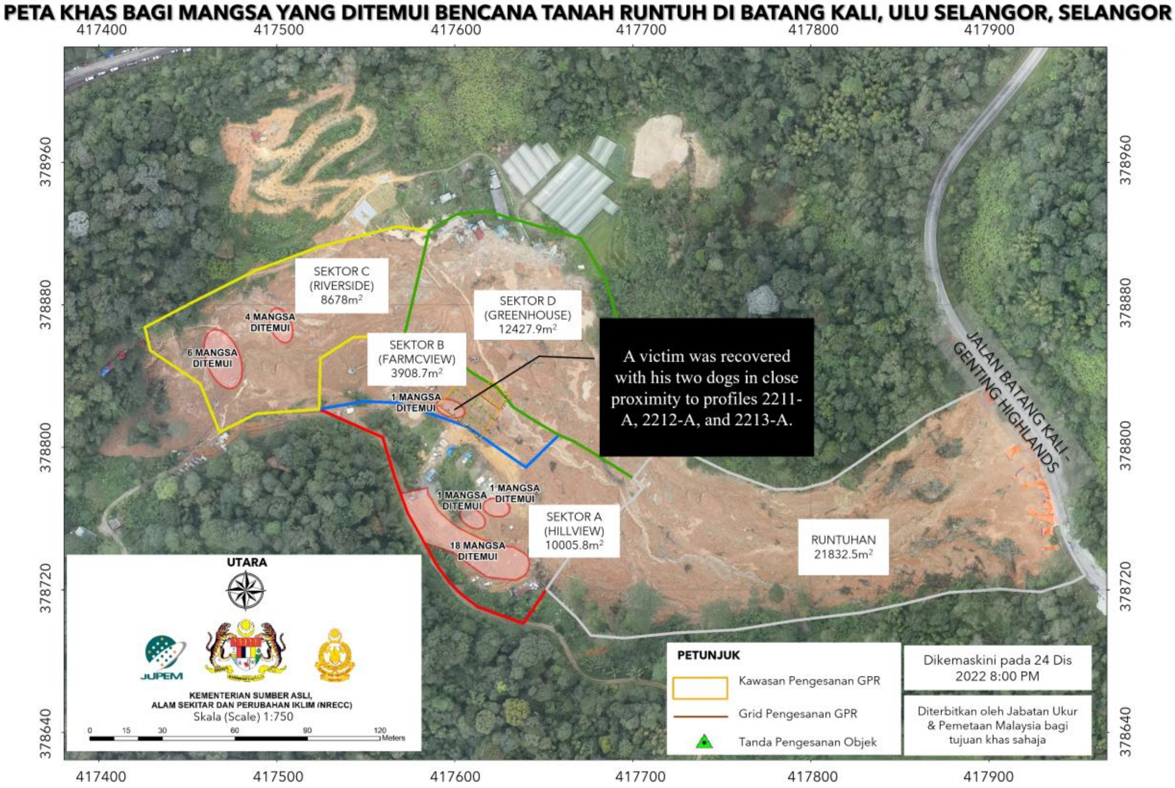


Figure 7: Special map of the recovered victims of the Batang Kali landslide and the GPR AOI

Reflection of GPR images in 3D or C-scan will aid in enhancing SAR detection capabilities. C-scan GPR or 3D GPR is a three-dimensional image generated by integrating numerous simultaneous B-scan photographs in the x and y plane, enabling the visualisation of top and side views of the image. Using Time slice y-cut on 3D processing in the Reflex3DScan ReflexW module, Figures 8 and 9 illustrate the reflection's location with increased accuracy and clarity. In practice, the production of a map for the C-scan or 3D-scan display mode for SAR detection involves the construction of an amplitude map at a specific time. Figure 10 depicts that the collection of this amplitude is dependent on the interpretation of the signal reflected from the 2D image or B-Scan. The reflection signal group in Figure 10 (a) appears to be longer and broader, which is most probably attributable to the victim's head, body, and blood or a large object, such as a tent that has fallen on the victim. In comparison, the group of reflection signals depicted in Figure 10 (b) and (c) appears smaller and fabricated, possibly due to the potential location of the victim's feet or the tent legs colliding with the victim.

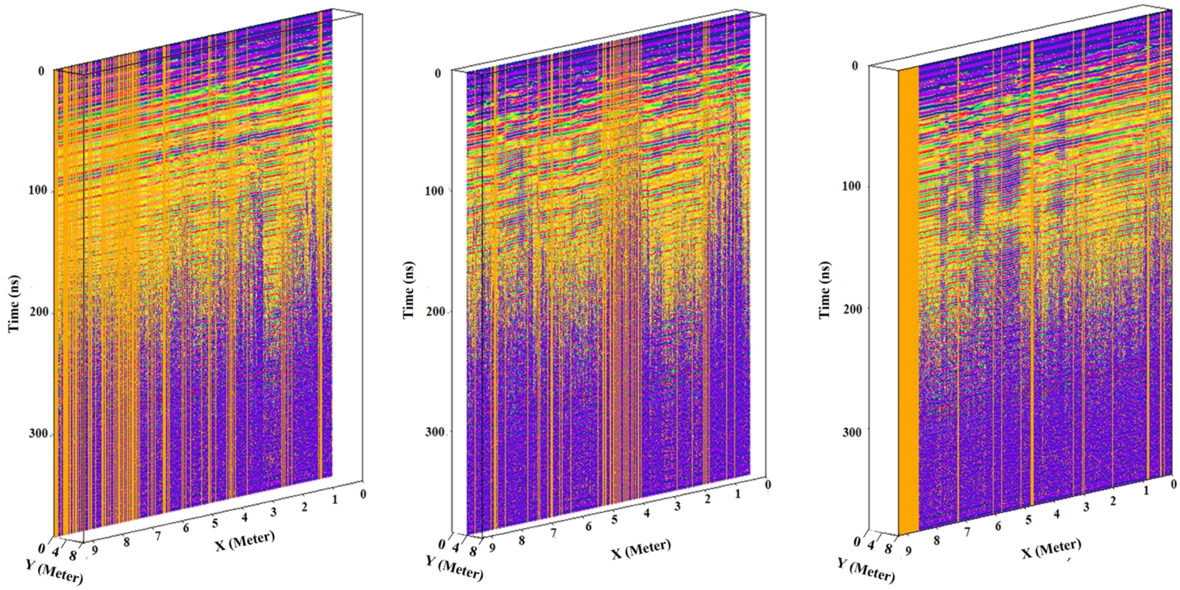


Figure 8: Time slice y-cut display of GPR scan for line (Right to Left: 2211-A, 2212-A, and 2213-A) for side view

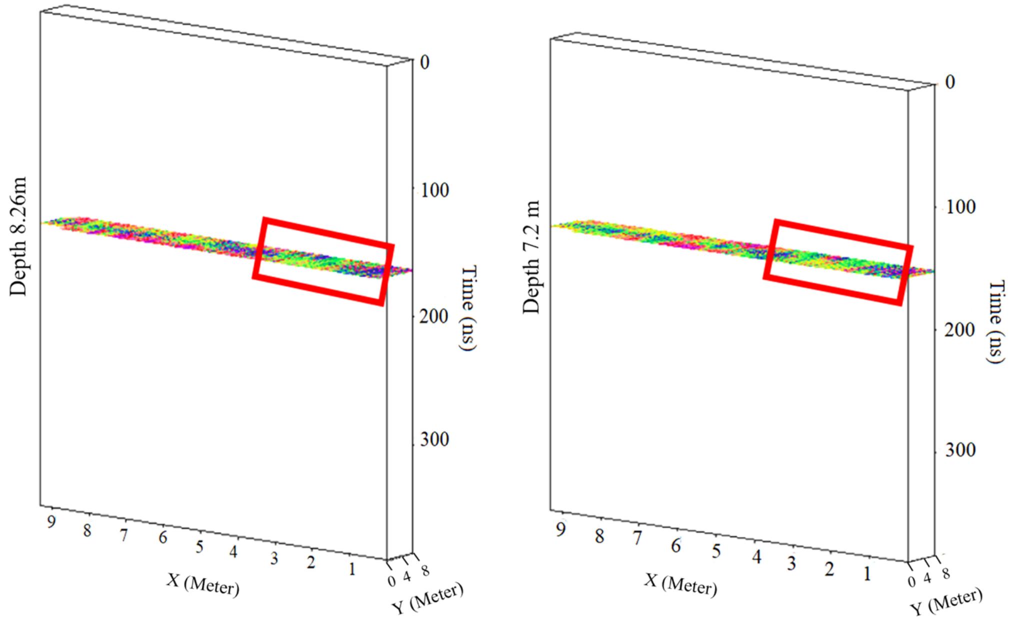
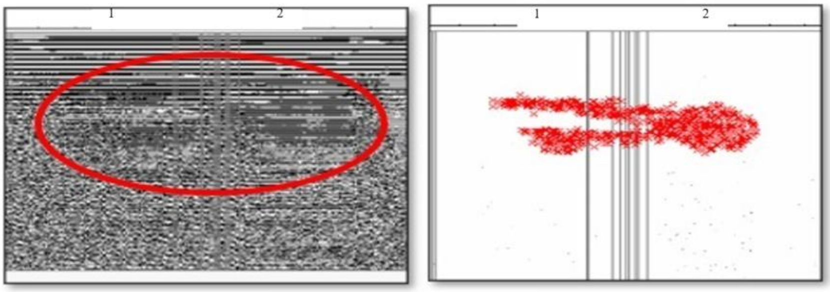
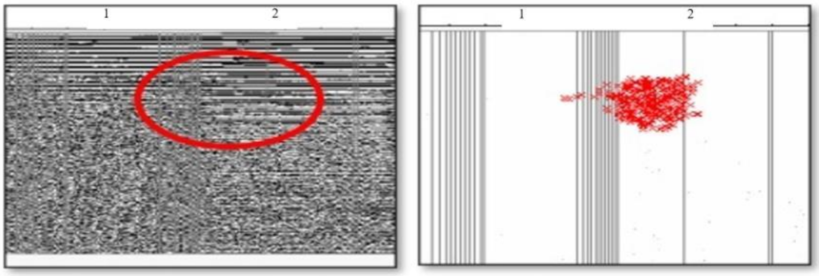


Figure 9: Time slice display of GPR scan for potential victim found in 8.26m and 7.2m depth

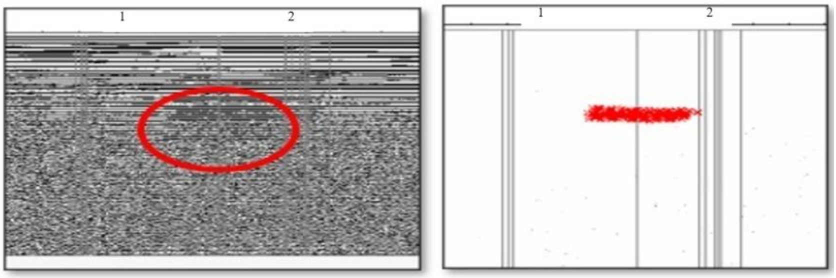
Meanwhile, Figure 11 demonstrates the construction of a 3D GPR image map (C scan) for detecting possible landslide victims as a result of the amplitude group. However, creating this 3D GPR map is subjective and heavily reliant on the operator's comprehension of the GPR signal image, especially considering the GPR AOI's soil type and inheritance properties. In summary, 3D visualisation was conducted to visually interpret and examine anomalies, including their depth and the type of foreign structure. Users can interpret anomalies with high accuracy by studying its 3D model, as shown in Figure 11, from various angles. Figure 11(a) is a front view of the potential victim location, while Figure 11(b) is a view of the 3D model from the rear. According to Okay et al., [30], any acquired results of 3D visualisation from the 3D model of the GPR scanned items are likely to be extremely close to the actual objects located on the sub-surface, thus, increasing the accuracy of decision-making.



(a) Profile Line 2211-A

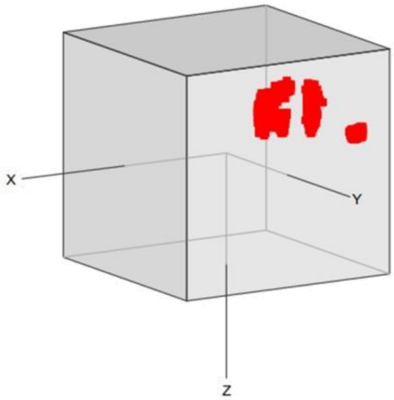


(b) Profile Line 2212-A

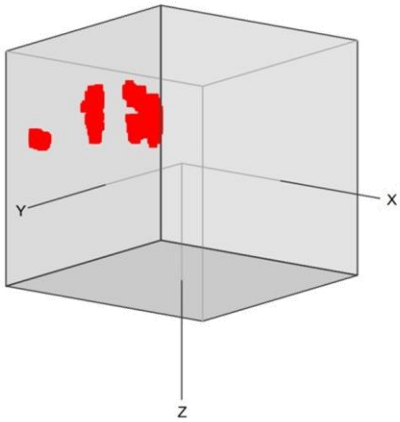


(c) Profile Line 2213-A

Figure 10: Amplitude map from GPR-2D interpretation of landslide victim detection



(a) Frontal Side View



(b) Rear Side View

Figure 11: 3D Map of GPR scan based on pick point for landslide victim detection

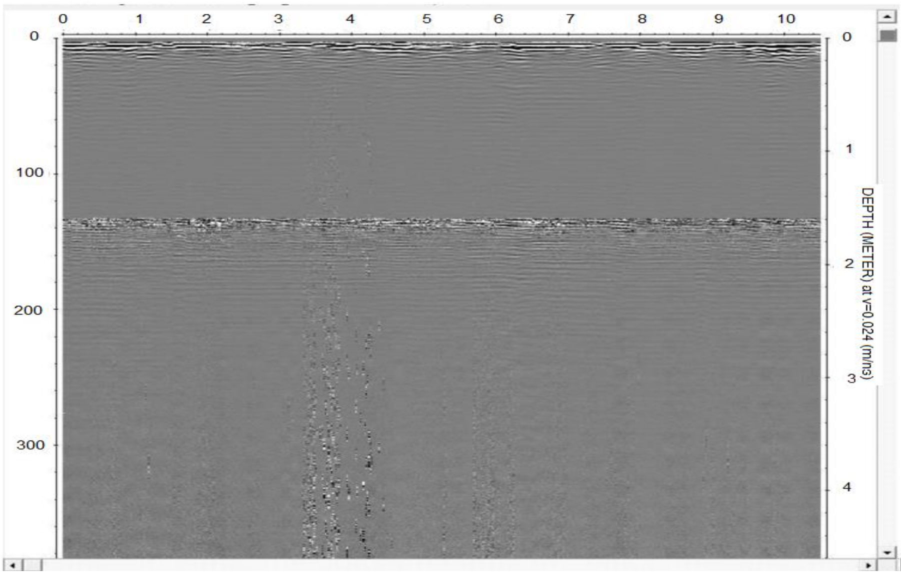


Figure 12: 2D Radargam of MALA RAMAC X3M with 500MHz antenna

Aside from this, it should be noted that, as a general rule, antennas with a lower frequency will penetrate deeper into the subsurface but will respond poorly to smaller objects and targets of interest due to their larger wavelength. Given that the collapsed slope of Father's Organic Farm exceeds 30 metres in height, JUPEM's GPR equipment is adequate. Despite this, a comparison study was conducted inside grid A11 to A17, as depicted in Figure 3, using another set of JUPEM-owned GPR, the MALA RAMAC X3M with 500MHz antenna. The maximum depth of the GPR penetrated was only 4.6m, and no hyperbola was detected, except for different types of soil within the 2m depth, as shown in Figure 12. The unsatisfactory result was consistent with the general principle that higher frequencies cannot penetrate as deeply into the earth because the signal scatters rapidly and is more easily absorbed [31].

5. Discussion and Conclusion

Although a landslide victim and his two dogs were successfully located by the SAR team on 21st December 2022 near the profile grids 2211-A to 2213-A, as depicted in Figure 7, it was inconclusive to determine whether the victim was recovered solely based on the GPR markers and depth information or complemented with the help of sniffer dogs and others. Confirmation was unattainable because access to ground zero was no longer allowed during or after excavation. It was restricted for concern of further slippage in the GPR area of interest as a result of continuous heavy rain a day before, as well as a desire to maintain the trained dogs' sense of scent during searching. In addition, ground zero was deemed a non-static and unstable background as the landscape's surface, subsurface, and depth may have occasionally changed due to excavations or continuous slippage. Nevertheless, even though the soft surface condition and soil type were perceived as not conducive to detection, this paper concludes that using terrestrial-based GPR as a search and recovery alternative for buried landslide victims is still feasible because hyperbolas are still detectable at low frequency. In addition, using plywood to avoid direct contact with the landslide surface and levelling the terrain improved the scanning results and made it possible to determine that the landslide soil type was constituted of saturated mixed soil components, as opposed to muddy or clay as was commonly believed.

According to Datuk Norazam Khamis, the Director of Selangor Fire and Rescue Department, the GPR datasets acquired at the Batang Kali landslide incident did provide first responders with situational awareness and reduced time for searching and recovering victims by narrowing down the focus of search areas [32]. The statement concurs with this study that terrestrial-based GPR is feasible for disaster recovery missions. It may pave the way for a new line of application and research revolving around search and rescue or search and recovery in Malaysia, including manmade disasters such as the collapse of urban infrastructure. The challenge would be to have a skilled operator who can detect a hyperbola or anomaly in a crisis where time is of the essence. In addition, the operator must be able to evaluate and implement best practices for achieving optimal GPR results in a disaster area. Establishing a grid, operating the scan, processing the data, and interpreting the findings are also required. Therefore,

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) | © Geoinformatics International

knowledge transfer and technical succession planning are crucial to transfer these crucial skills to successors operators. Capacity development should be prioritised in these areas if GPR is to become a viable alternative for natural or manmade disaster SAR missions.

Compared to a 2D radargram, a 3D visualisation of a GPR scan can improve SAR detection capabilities, as demonstrated in this paper. Unlike B-scans, three-dimensional (3D) C-scans facilitate a more straightforward and accessible semantic interpretation of the subsurface based on the parameters set to detect potential victims. However, misinterpretation of the GPR C-scan could cause serious issues. Thus, without clear standards for the survey procedure, it can be challenging to determine the reliability of the GPR dataset. Therefore, for future research, it is suggested that a guideline be developed to incorporate the use of terrestrial-based GPR in a SAR mission. The PTO prepared by JUPEM specifically for landslide incidents may be expanded with the use of GPR technology to provide location-based information that does not stop at the x and y plane but also depth. In other words, to include a 3D visualisation of the subsurface for better and informed decision-making.

The study also demonstrated that a 250 MHz GPR was more effective for the landslide area's saturated mixed soil as it was simpler to identify prominent reflections on the reflection profiles. For landslide areas that are typically damped and wet due to the magnitude of rainfall, the 500 MHz antenna may be a better choice for detecting less than 0.50 m features, whereas the 250 MHz antenna is excellent at detecting features deeper than 1m. Nevertheless, the estimated collapsed debris height should also be accounted for to determine the appropriate antenna frequency.

In conclusion, it is hoped that this paper has contributed to the body of knowledge regarding the use of terrestrial-based GPR technology for SAR missions, particularly in the recovery of landslide victims. Notably, 3D geovisualisation has a future beyond the traditional purpose of GPR, and the resulting 3D information could aid first responders in decision-making and situational awareness during a disaster event.

Acknowledgements

The authors would like to thank the Department of Survey and Mapping Malaysia, particularly the Utility Mapping Division. A special thanks also goes to Abd Rahman bin Mohd Jazuli @ Mahmood, Mohd Riza bin Halim, Mohd Harris Hafizi bin Mohd Shahidan and Loshini A/P Panirselvam for providing the necessary information regarding the use of GPR during the SAR mission at Batang Kali landslide incidents.

References

[1] Radhi, N. A. M. and Murugan, D., (2022). Nik Nazmi: Batang Kali landslide Displaced 450,000 Cubic Meters of Earth. *News Straits Time.* Available from: https://www.nst.com.my/news/nation/2022/12/861444/nik-nazmi-batang-kali-landslide-displaced-450000-cubic-meters-earth.

[2] TV3 B., (2022). *Tragedi Batang Kali: Operasi SAR Diteruskan Untuk Pembersihan, Siasatan*. Nasional. Nasional ed. Kuala Lumpur.

[3] Awang, A. H. C., (2022). Banjir Baling: Gunung Inas Tidak Berada Dalam Kawasan Berisiko. *Astro Awani.* Available from: https://www.astroawani.com/berita-malaysia/banjir-baling-gunung-inas-tidak-berada-dalam-kawasan-berisiko-takiyuddin-370013.

[4] Tongkul, F., (2017). Active Tectonics in Sabah—Seismicity and Active Faults. *Bulletin of the Geological Society of Malaysia*. Vol. 64, 27-36. DOI: https://doi.org/10.7186/bgsm64201703.

[5] Izumi, T., Matsuura, S., Mohd Yusof, A. F., Razak, K. A., Moriguchi, S., Kure, S., Jamal, M. H., Motoyama, E. and Supar, L. M., (2019). Disaster Risk Report by IRIDeS, Japan; Universiti Teknologi Malaysia; Selangor Disaster Management Unit, Selangor State Government, Malaysia. Kuala Lumpur. 1-108, https://jppsedar.net.my/wp-content/uploads/2020/06/69091disasterriskreportselangorfinal19mb.pdf.

[6] Sharuddin, Z., (2016). Pelbagai Agensi Kerajaan Usaha Kesan Pencemaran Di Nilai. *Berita Harian.* Available from: http://origin.bharian.com.my/taxonomy/term/2644/2016/10/205468/pelbagai-agensi-kerajaan-usaha-kesan-pencemaran-di-nilai.

[7] Nasir, M. M., (2020). JUPEM Lancar Buku PTO 10 Bencana. *Harian Metro.* Available from: https://www.hmetro.com.my/mutakhir/2020/09/623311/jupem-lancar-buku-pto-10-bencana-metrotv.

[8] Cist, D. B., (2009). Non-Destructive Evaluation After Destruction: Using Ground Penetrating Radar for Search And Rescue. *Proceedings of the 7th International Symposium on Non-destructive Testing in Civil Engineering, Nantes, France*. Vol. 14(7). https://www.ndt.net/?id=7723.

[9] Jamil, H., Yusoff, M. Y. M., Nomanbhoy, Z. and Yusoff, N. A. M., (2015), Current Progress on Underground Utility Mapping in Malaysia. *FIG Working Week 2015: From the Wisdom of the Ages to the Challenges of the Modern World Sofia, Bulgaria, 17-21 May 2015*, 1-13. http://www.fig.net/resources/proceedings/fig_proceedings/fig2015/papers/ts02h/TS02H_jamil_mohd_yusoff_et_al_7904.pdf

[10] Hassan, H., Rahman, S. A., Ahmad, F., (2022). Spatial Information for Disaster Risk Management: The Constraints, Limitations and Opportunities from JUPEM Perspective. *IOP Conference Series: Earth and Environmental Science*; Vol. 1064. DOI: 10.1088/1755-1315/1064/1/012032.

[11] Rahim, R. N. R., (2022). Tragedi Tanah Runtuh: Pengesan GPR Pertama Kali Digunakan Di Negara Ini. *Harian Metro*. Available from: https://www.hmetro.com.my/mutakhir/2022/12/916391/tragedi-tanah-runtuh-pengesan-gpr-pertama-kali-digunakan-di-negara-ini.

[12] Hu, D., Chen, L., Du, J., Cai, J. and Li, S., (2022). Seeing through Disaster Rubble in 3D with Ground-Penetrating Radar and Interactive Augmented Reality for Urban Search and Rescue. *Journal of Computing in Civil Engineering*, Vol. 36(5), DOI:10.1061/(ASCE)CP.1943-5487.0001038.

[13] Schennen, S., Tronicke, J., Wetterich, S., Allroggen, N., Schwamborn, G. and Schirrmeister, L., (2016). The Potential of Ground-Based 3D GPR Imaging: 2D vs. 3D Examples from the Yedoma Region. *XI International Conference on Permafrost*. Potsdam, 20 June 2016 - 24 June 2016. DOI: 10.2312/GFZ.LIS.2016.001

[14] Hu, D., Li, S., Chen, J. and Kamat, V. R., (2019). Detecting, Locating, and Characterizing Voids in Disaster Rubble for Search and Rescue. *Advanced Engineering Informatics*, Vol. 42. https://doi.org/10.1016/j.aei.2019.100974.

[15] Akbari, A., Meshinchi-As, M. and Riyahi, M., (2014). An Improved Hyperbolic Summation Imaging Algorithm for Detection of the Subsurface Targets. *Journal of Remote Sensing & GIS*, Vol. 3(4), 1-7. DOI:10.4172/2169-0049.1000132

[16] AlAli, Z. T. and Alabady, S. A., (2022). A Survey of Disaster Management and SAR Operations Using Sensors and Supporting Techniques. *International Journal of Disaster Risk Reduction*, Vol. 82. https://doi.org/10.1016/j.ijdrr.2022.103295.

[17] Parenti L., Wilson M., Foreman A.M., Wirth, O. and Jean Meade, B. J, (2015). Selecting Quality Service Dogs: Part 1: Morphological and Health Considerations. The Dog Trainer's Resource: APDT Chronicle of the Dog Collection. *Summer;2015(summer)*. 71-7.

[18] Miller, P. S., (1996). Disturbances in the Soil: Finding Buried Bodies and other Evidence Using Ground Penetrating Radar. *J. Forensic Sci*., Vol. 41(4), 648-652.

[19] Joret, A., Ahmed, S., Katiran, N. and Sulong, M. S., (2022). Human Detection Techniques for Search and Rescue of Trapped Victims Under Debris: A Review. *Evolution of Information, Communication and Computing System*. Vol. 3(1) 54–65. Retrieved from https://publisher.uthm.edu.my/bookseries/index.php/eiccs/article/view/34.

[20] Lombardi, F., Podd, F., Solla, M., (2022). From Its Core to the Niche: Insights from GPR Applications. *Remote Sensing*, Vol. 14(13). https://doi.org/10.3390/rs14133033.

[21] Jaedicke, C., (2004). *Avalanche Victim Search by Ground Penetrating Radar*. The International Snow Science Workshop, Jackson Hole, Wyoming.

[22] Schultz, J. J., (2012). *Detecting Buried Remains Using Ground-Penetrating Radar*. The U.S. Department of Justice. 1-235. https://www.ojp.gov/pdffiles1/nij/grants/238275.pdf.

[23] Trisha, N., (2022). Batang Kali Landslide: Eight Deaths so far, Rubble Piled Up to 30m High. *The Star*. 2022 16th December 2022. Available from: https://www.thestar.com.my/news/nation/2022/12/16/batang-kali-landslide-two-fatalities-confirmed-rubble-piled-up-to-30m-high#:~:text=PETALING%20JAYA%3A%20Eight%20people%20have,92%20victims%20had%20been%20found.

[24] JUPEM, (2021). *Pekeliling Ketua Pengarah Ukur dan Pemetaan Bil 13/2021*. Garis Panduan Tatacara Ujian Alat Pengesanan Utiliti Bawah Tanah. Kuala Lumpur.

[25] Samet, R., Çelik, E., Tural S., Şengönül, E., Okay, M. O. and Damci, E., (2017). Using Interpolation Techniquest to Determine the Optimal Profile Interval in Ground-Penetrating Radar Applications. *Journal of Applied Geophysics*, Vol. 140, 154-167. DOI:10.1016/j.jappgeo.2017.04.003.

[26] Deros, B. M., Mohamad, D., Ismail, A. R., Soon, O. W., Lee, K. C. and Nordin, M. S., (2009). Recommended Chair and Work Surfaces Dimensions of VDT Tasks for Malaysian Citizens. *European Journal of Scientific Research*, Vol. 34, 156-167.

https://static.aminer.org/pdf/PDF/000/239/777/eye_discomfort_and_vdt_work.pdf.

[27] Salako, A. O., Osotuyi, A. G. and Adepelumi, A. A., (2019). Seepage Investigations of Heterogeneous Soils Beneath Some Buildings Using Geophysical Approaches: Example From Southwestern Nigeria. *International Journal of Geo-Engineering*, Vol. 10, 1-20. https://doi.org/10.1186/s40703-019-0107-5.

[28] Jiao L., Ye Q., Cao X., Huston, D. and Xia, T., (2020). Identifying Concrete Structure Defects in GPR Image. *Measurement*. Vol. 160. https://doi.org/10.1016/j.measurement.2020.107839

[29] MalayMail. (2022). Batang Kali landslide: SAR Operation Suspended Due to Unfavourable Weather; to Resume Tomorrow, Say Police. *MalayMail.* 2022 21st December 2022. Available from: https://www.malaymail.com/news/malaysia/2022/12/21/batang-kali-landslide-sar-operation-suspended-due-to-unfavourable-weather-to-resume-tomorrow-say-police/46540.

[30] Okay, M. Ö. and Samet, R., (2017). 3D visualisation approach to GPR data. *Communications Faculty of Sciences University of Ankara Series A2-A3 Physical Sciences and Engineering*. Vol. 59(2), 29-40.

[31] Schultz, J. J. and Martin, M. M., Controlled GPR Grave Research: Comparison of Reflection Profiles between 500 and 250MHz antennae. *Forensic Science International*, Vol 209(1), 64-69.

[32] Khamis, N., (2022). Batang Kali Landslide: Ground Penetrating Radar Being Used to Find Victims. In: BERNAMA, The STAR TV.